

# Tesis

## **ANALISA RESPON GETARAN TRANSVERSAL *BOILER FEED PUMP* PADA KONDISI BEBAN MAKSIMUM DAN BEBAN SEBAGIAN *FEEDWATER SYSTEM* PADA PLTU PAITON BARU**



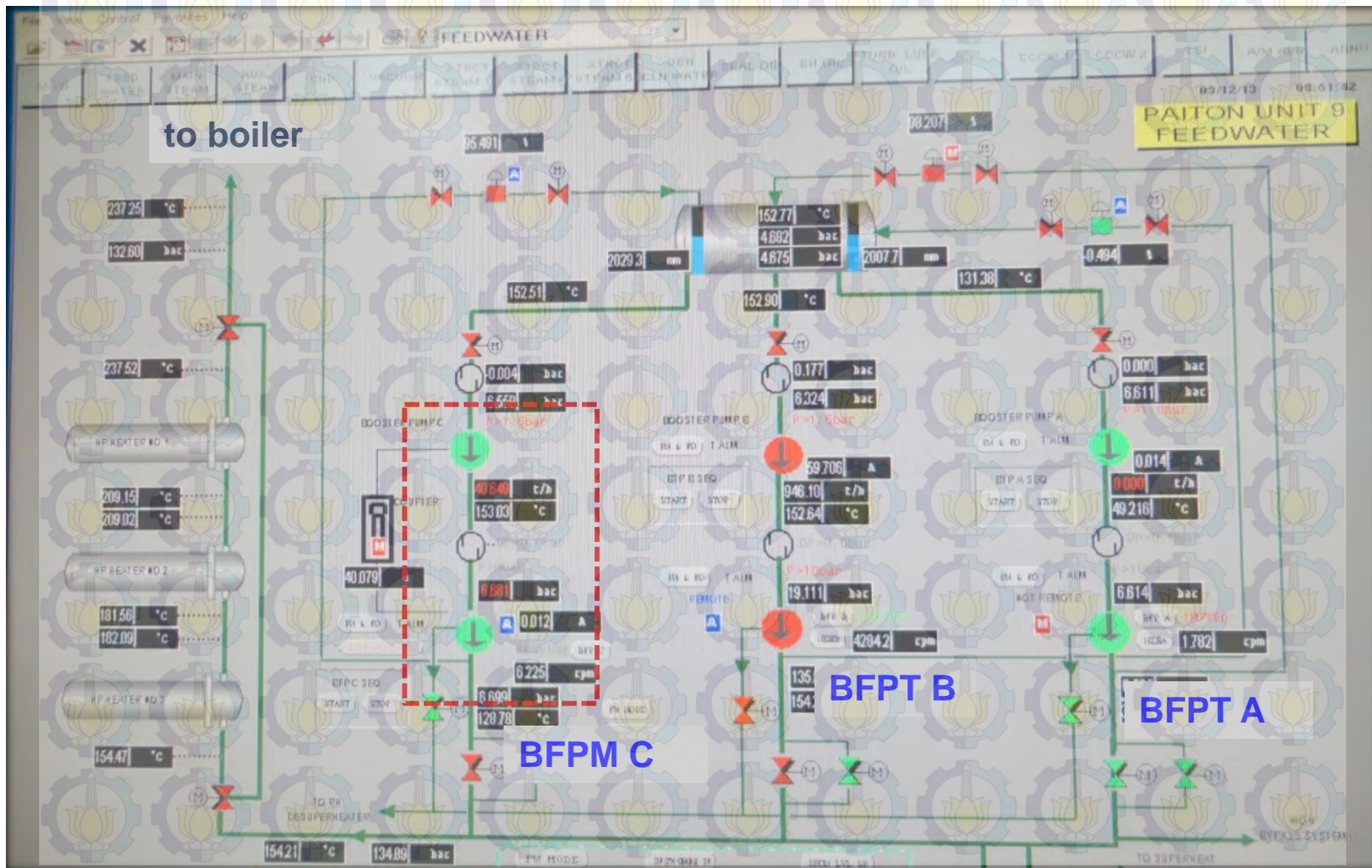
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**2112204802**

***Rekayasa Energi***

**Pembimbing: Dr. Eng. Harus Laksana Guntur, ST. M.Eng.**



# Pendahuluan – Feedwater System





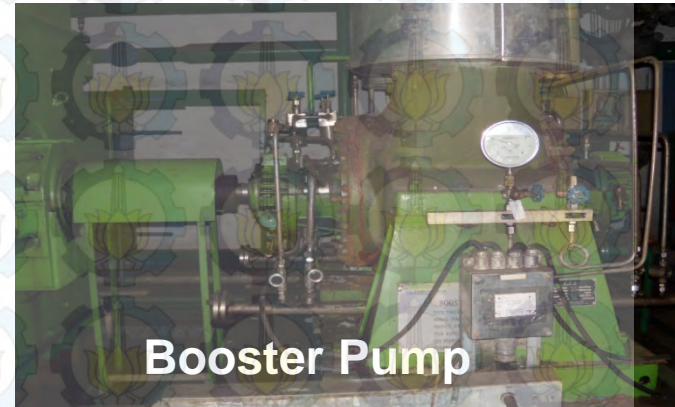
# Pendahuluan – Bentuk fisik Boiler Feed Pump



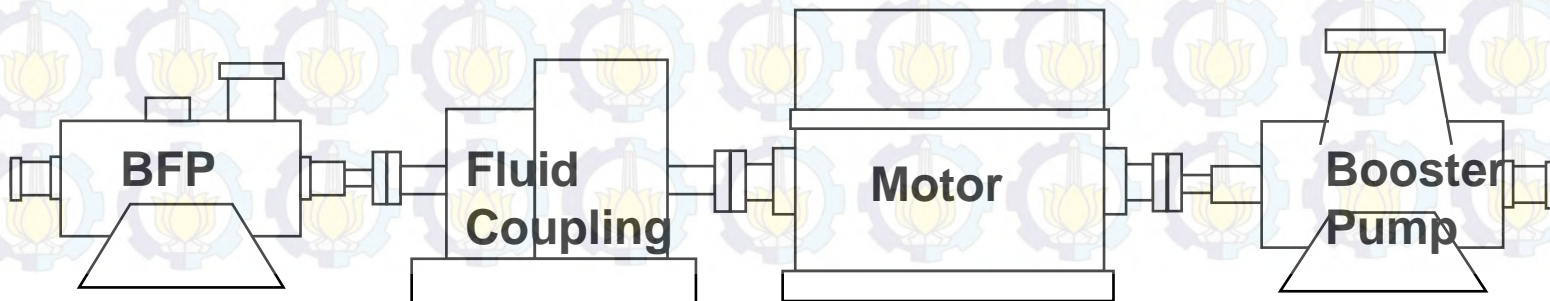
**Boiler Feed Pump**



**Variable Speed Coupling**

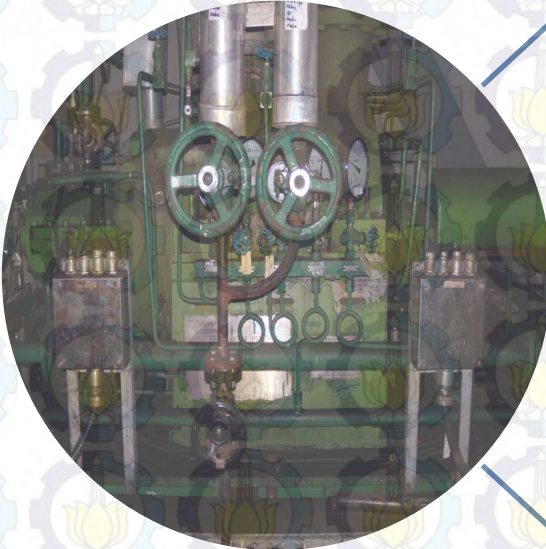


**Booster Pump**





## Fungsi Boiler Feed Pump-motor



### Start Up

- Resirkulasi feedwater ke deaerator
- Dioperasikan hingga beban unit 30% (190MW)

### Shutdown

- Change over saat beban 30%

### Back Up

- Ketika terjadi gangguan

1. BFPM sering dioperasikan pada beban rendah atau pada kondisi *off designnya*
2. *Noise* lebih tinggi saat beban rendah



1

- Bagaimana memodelkan respon getaran pada *Boiler Feed Pump – Motor* (BFPM) yang ada di PLTU Paiton Baru

2

- Bagaimana respon getaran *Boiler Feed Pump – Motor* yang ada di PLTU Paiton Baru dengan kondisi separuh beban dan beban maksimum

1

- Memodelkan dan mensimulasikan respon getaran *Boiler Feed Pump-motor*.

2

- Mengukur respon getaran pada *Boiler Feed Pump-Motor* pada kondisi pembebanan maksimum dan separuh beban

3

- Membandingkan dan menganalisa hasil simulasi dan pengukuran respon getaran



1. Memberikan informasi mengenai respon getaran pada *Boiler Feed Pump–Motor (BFPM)* melalui studi numerik dan empirik pada kondisi pembebanan maksimum dan beban sebagian pada *feedwater system* PLTU Paiton Baru.
2. Dengan pemodelan dan simulasi dapat diketahui tren vibrasi pada peralatan *boiler feed pump motor* untuk berbagai kondisi pembebanan.
3. Memberikan metode alternative penyelesaian masalah getaran pada pompa di area pembangkitan listrik terutama yang berkaitan dengan kondisi pengoperasian yang bervariasi



1

- BFPM yang dimodelkan adalah BFPM pada PLTU Paiton Baru
- Peralatan yang dimodelkan meliputi *Booster pump*, *variable speed fluid coupling*, dan *multistage centrifugal pump*

2

- Pompa dan kopling dimodelkan sebagai rigid body
- Sistem dianggap dalam kondisi ideal
- Gaya radial pada BFPM merupakan resultan gaya dari masing-masing impeler

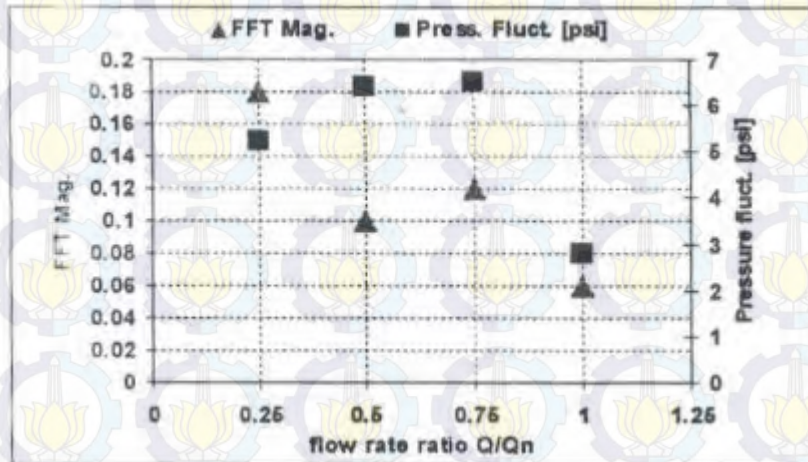
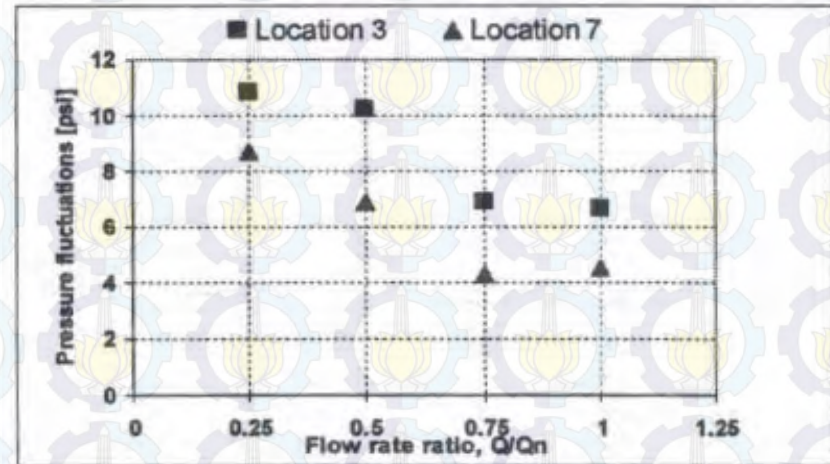
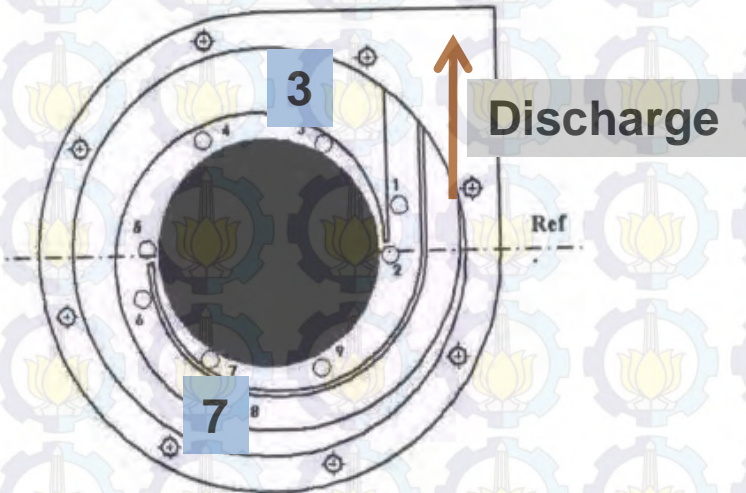
3

- Tidak membahas vibrasi pada arah torsional
- Tidak membahas vibrasi akibat mechanical unbalance rotor
- Gaya aksial pada booster pump diasumsikan kondisi setimbang

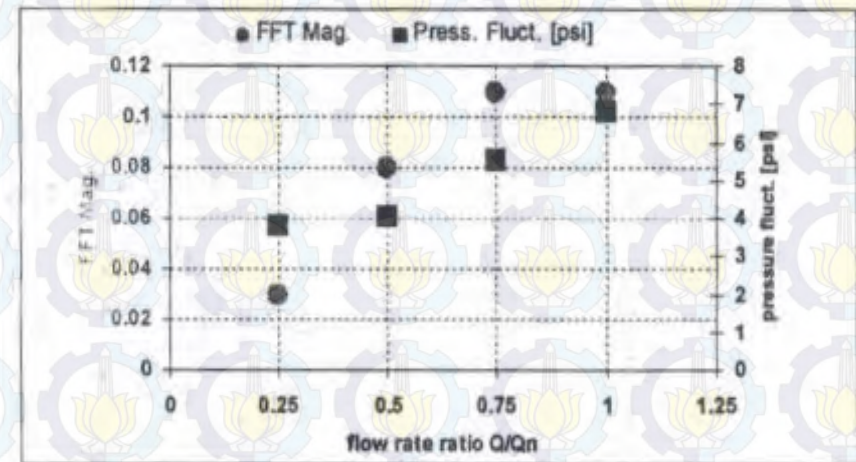


**Attia khalifa (2009):**

Penelitian pada **BFP** mengenai pengaruh pengurangan flowrate terhadap fluktuasi & distribusi tekanan untuk mengidentifikasi kondisi operasi yang kritis



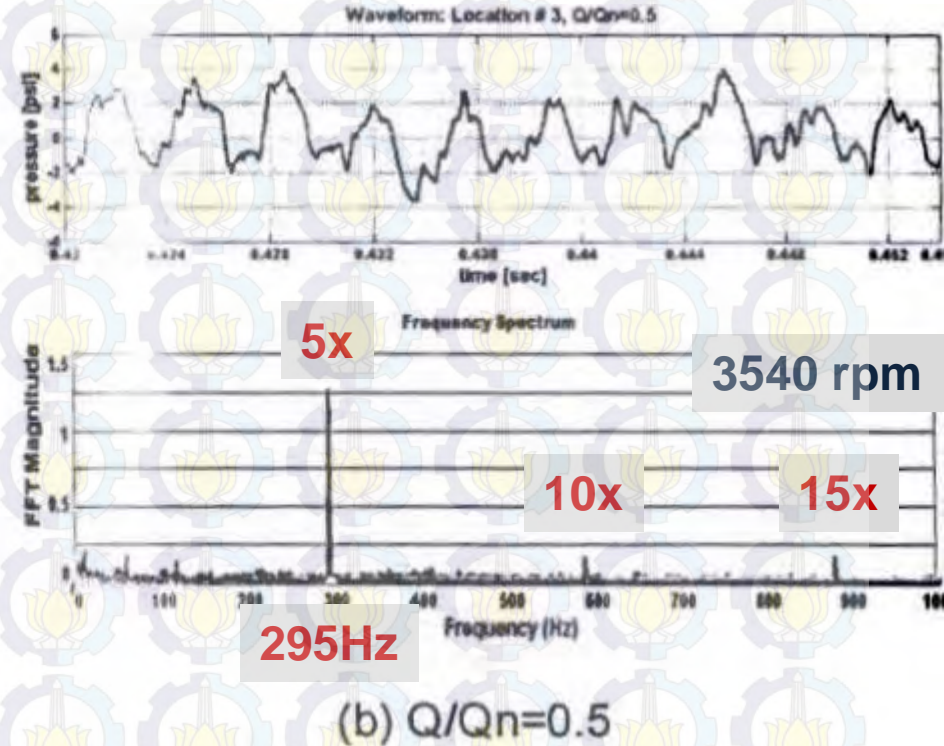
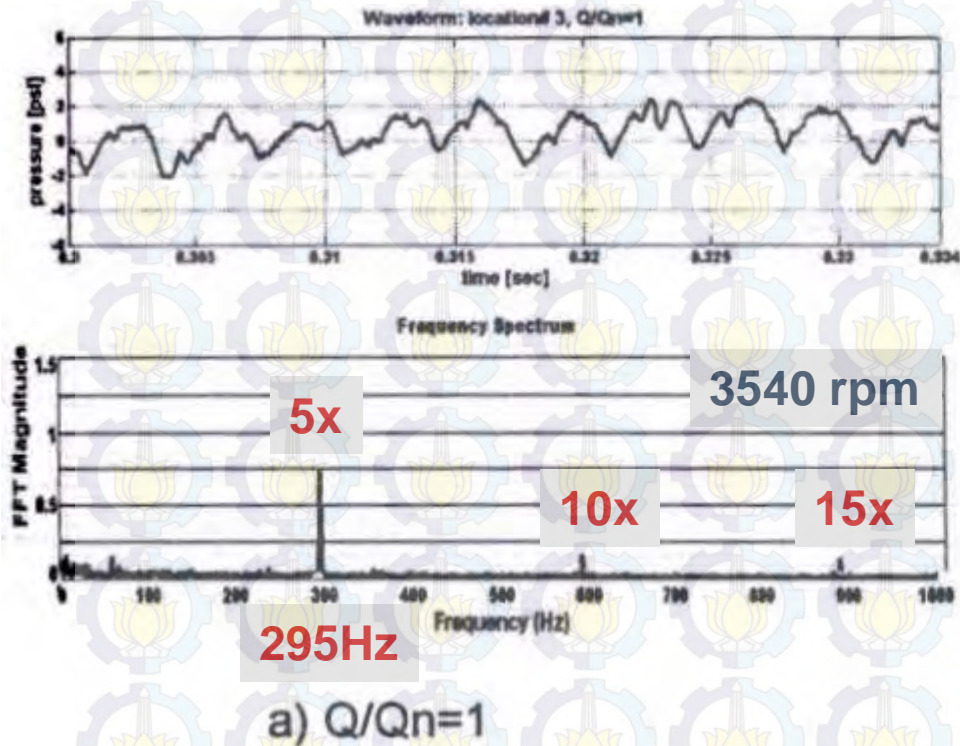
**Suction Pipe**



**Discharge Pipe**



Attia khalifa (2009)

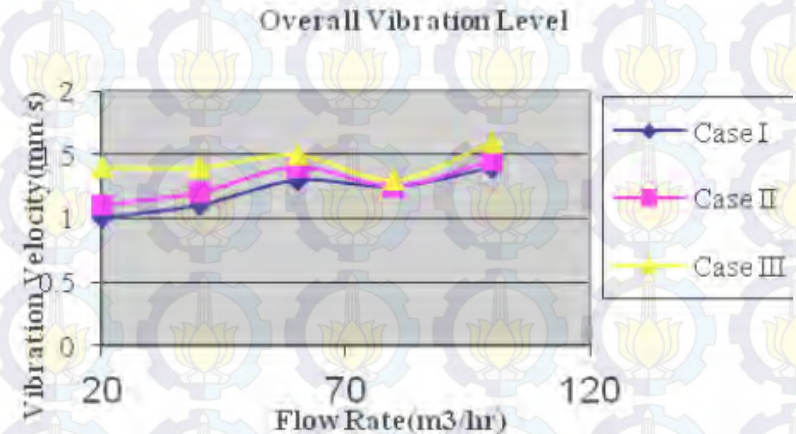
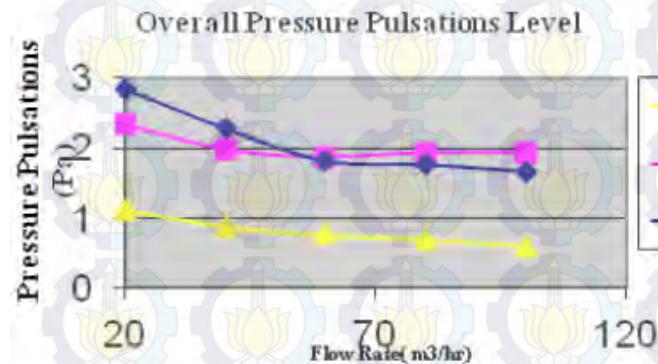


Flowrate 50% Load menimbulkan blade passing frekuensi yang Lebih tinggi 2x daripada 100% flowrate



## Amit Suhane (2012)

Penelitian mengenai pengaruh flowrate terhadap pressure pulsasi, vibrasi dan Noise dengan variasi radial clearance



Variasi radial clearance

Case 1 = 6.8mm

Case 2 = 3.7mm

Case 3 = 1.5mm

Semakin besar radial clearance maka pressure pulsation, vibrasi, dan noise semakin kecil

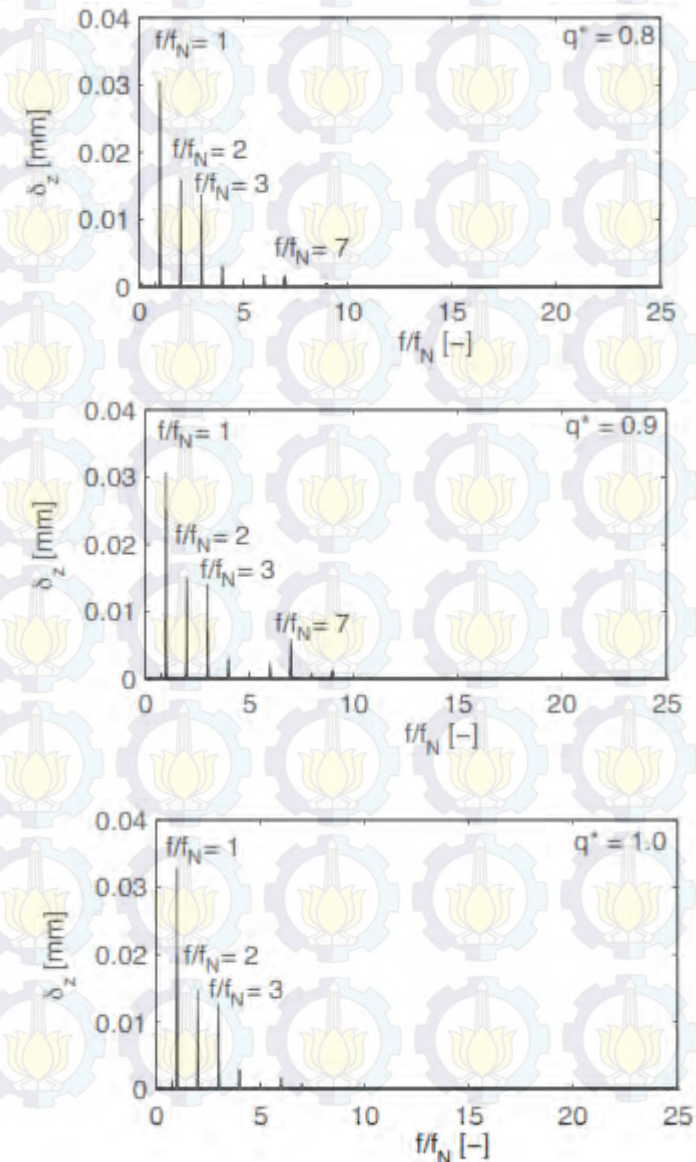


## Stefan Berten (2010)

Pengoperasian BFP pada kondisi off design akan menyebabkan Gangguan distribusi tekanan pada impeler yang menghasilkan vibrasi pada arah radial dan pada arah aksial

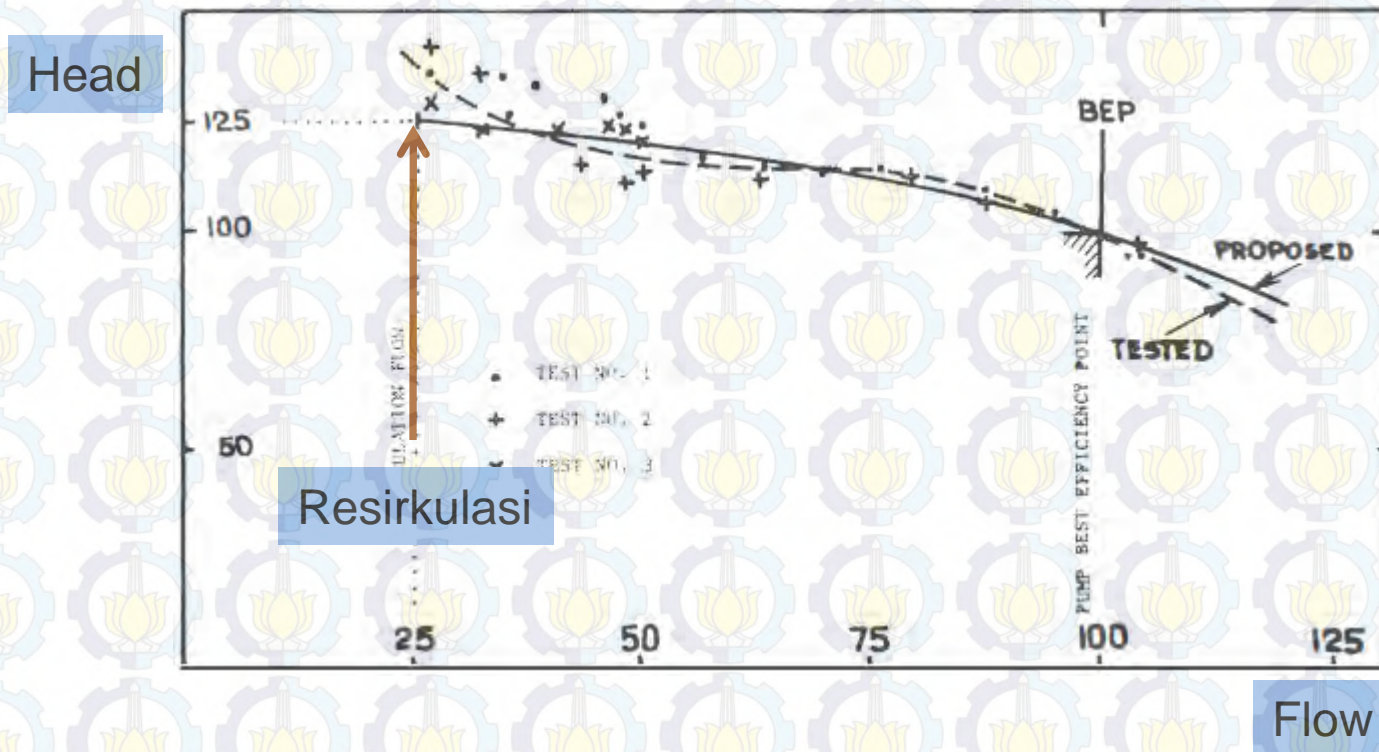
Munculnya zona resirkulasi pada *diffuser*, menambah vibrasi pada impeler *blade passing frequency*

## Vibrasi arah aksial



**Dr. Elemer Makay:**

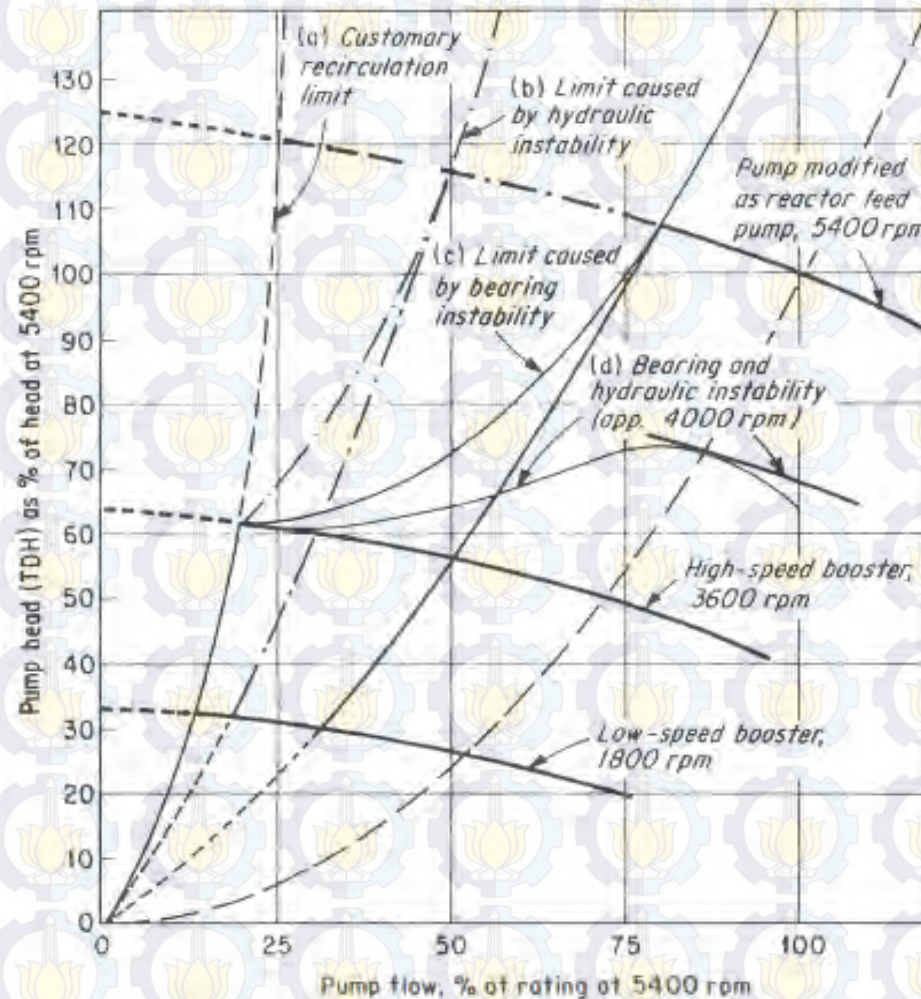
Penelitian mengenai problem pada Boiler Feed Pump untuk berbagai kondisi operasi



25%-55% Flowrate ketidakstabilan hidrolis semakin besar



Dr. Elemer Makay

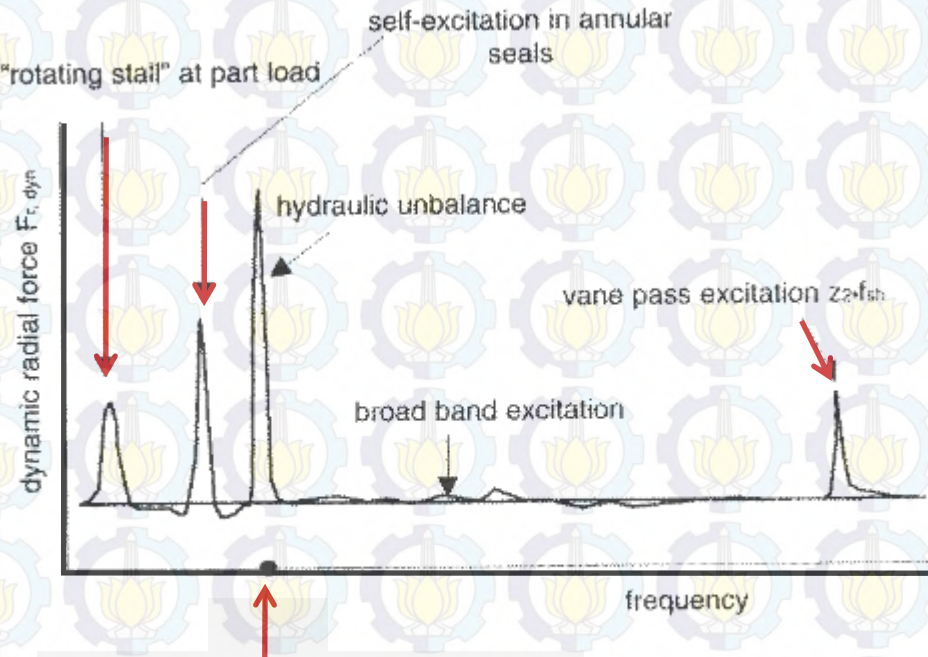


Penyebab ketidakstabilan rotor pompa :

*secondary flow, stall, leakage flow melalui wear ring, fluktuasi unsteady flow, blade passing frequency, turbulensi, kavitasi, dan hydraulic unbalance*



# Dasar Teori – *Fundamental Frequency*



## Frekuensi Putaran poros

Range Frekuensi	Penyebab Getaran
0.2	Rotating stall/ resirkulasi pada diffuser
0.45 – 0.95	Ketidakstabilan rotor
0.8	Annular seal, journal bearing interaction force
1x putaran poros	Mech & Hidrolik unbalance
Z x putaran poros*	Blade Pass Forces

**\*Z : Jumlah blade impeller**



$$F_d = k_d \times \rho \times g \times H \times d_2 \times B_2$$

Dimana :

$F_d$  = *impeller dynamic force*

$k_d$  = *hydraulic dynamic coefficient factor,*

$\rho$  = *fluid density,*

$H$  = *Head,*

$D_2$  = *impeler outlet diameter,*

$B_2$  = *Impeler outlet width (termasuk shroud).*

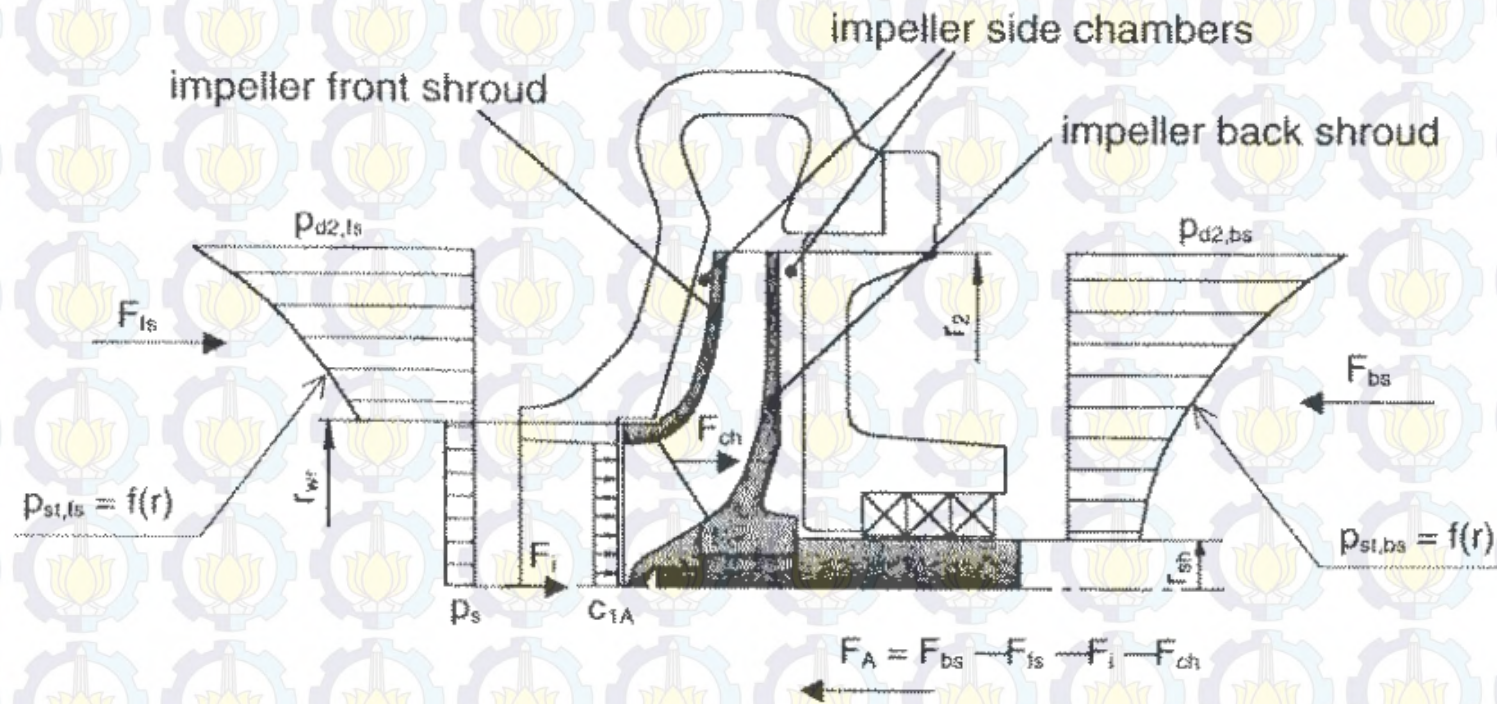
Normalized (rms) Impeller Hydraulic Dynamic Force Factor ( $K_d$ )

$Q/Q_{BEP}$	$\Omega/\omega = 0.02-0.2$	$\Omega/\omega = 0.2-1.25$	$\Omega/\omega = 1$	$\Omega_v$
0.2	0.02-0.07	0.02-0.05	0.01-0.12	0.2-0.12
0.5	0.01-0.04	0.01-0.02	0.01-0.12	0.1-0.08
1.0	0.002-0.015	0.005	0.01-0.13	0.1-0.06
1.5	0.005-0.03	0.01-0.02	0.01-0.15	0.2-0.10

$\Omega$  is the force frequency,  $\omega$  is the speed,  $\Omega_v$  is the Vane No. x  $\omega$ , and  $K_d$  values for  $\Omega/\omega = 0.2-1.25$  have  $\Omega/\omega = 1$  component filtered out.



# Dasar Teori – Gaya Aksial



Dimana komponen aksial thrust dapat dihitung sebagai berikut :

$$F_{bs} = \pi \times (r_2^2 - r_{sh}^2) \times \left( P_{d2,bs} - 0.5\rho \times \omega^2 \times k_{bs} \times (r_2^2 - 0.5(r_2^2 + r_{sh}^2)) \right)$$

$$F_{fs} = \pi(r_2^2 - r_{wr}^2) \cdot \left( P_{d2,fs} - 0.5\rho \cdot \omega^2 \cdot k_{fs} (r_2^2 - 0.5(r_2^2 + r_{wr}^2)) \right) + P_s \cdot \pi \cdot r_{wr}^2$$

Atau bisa didekati dengan :

$$F_A = (0.7 \sim 0.9) \times \Delta P_{tot} \times \pi \times (r_{wr}^2 - r_{sh}^2)$$



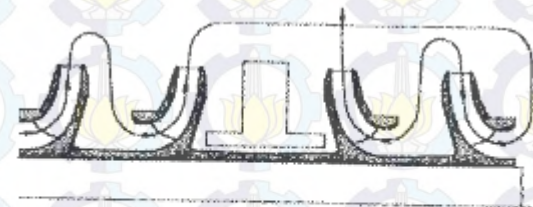
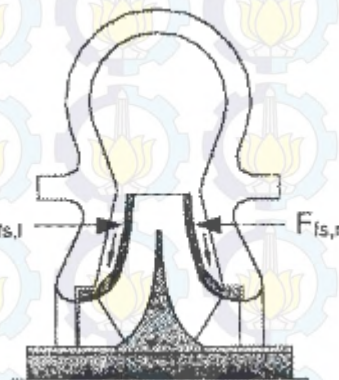
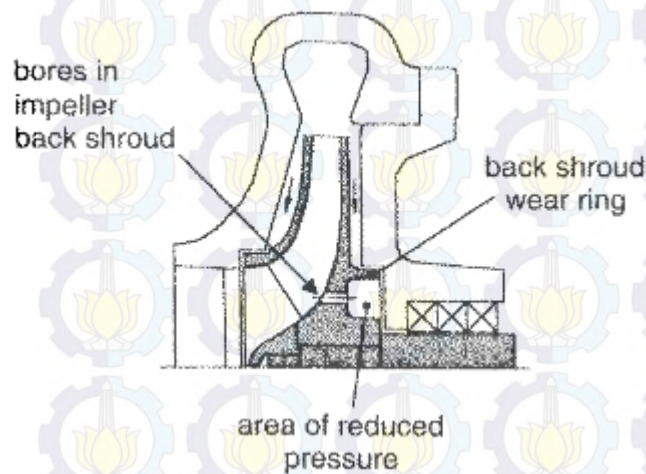
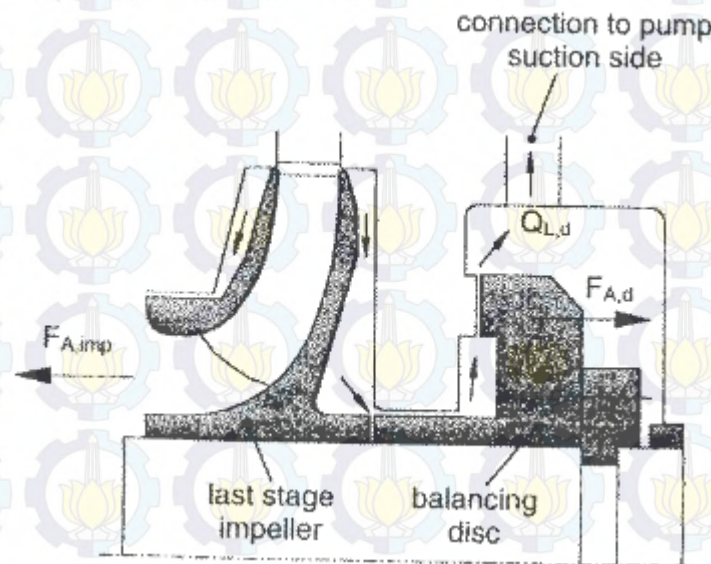


Fig. F.1.7 Multi-stage pump in back-to-back impeller arrangement



Fig. F.1.8 Multi-stage pump with all impellers in series

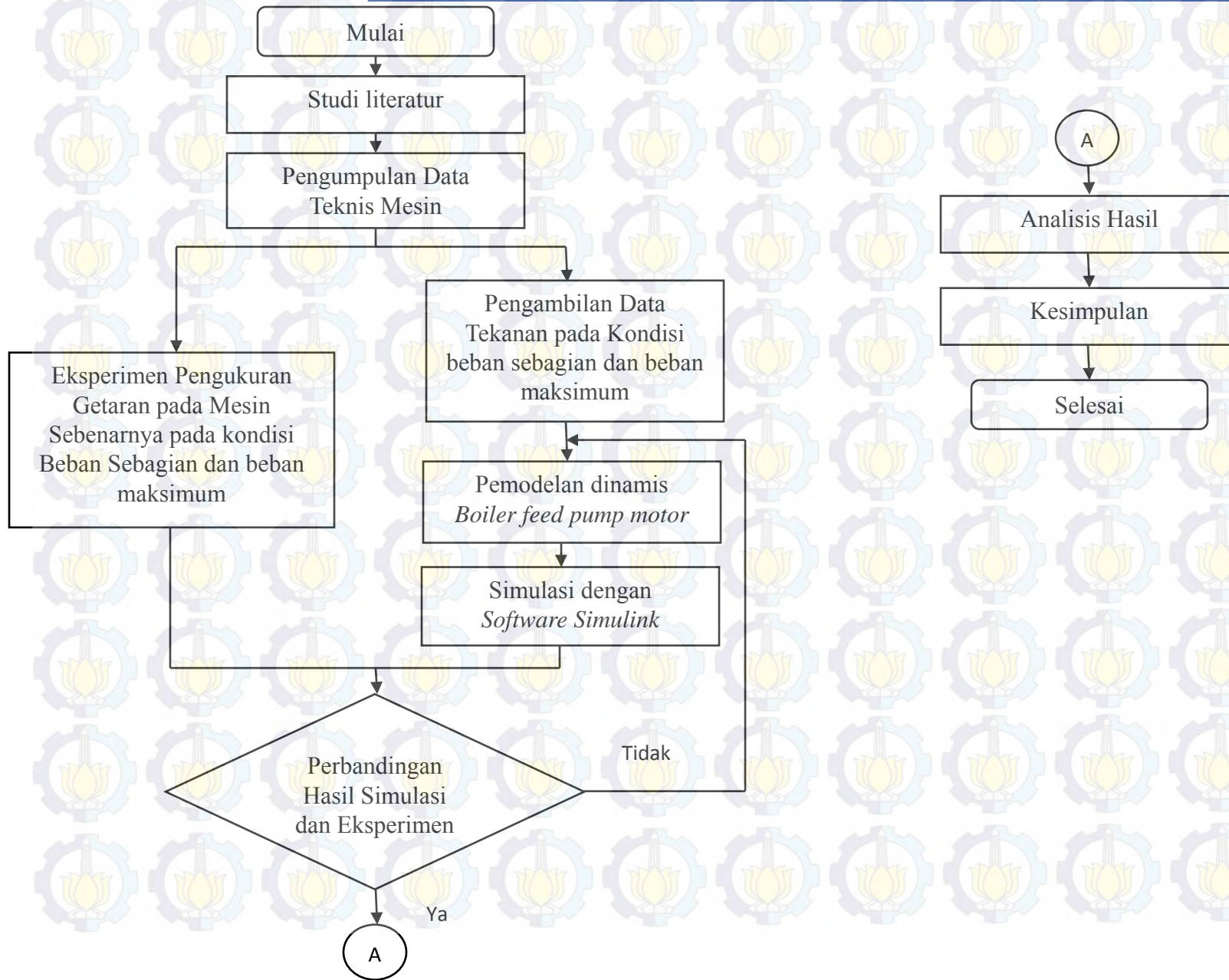


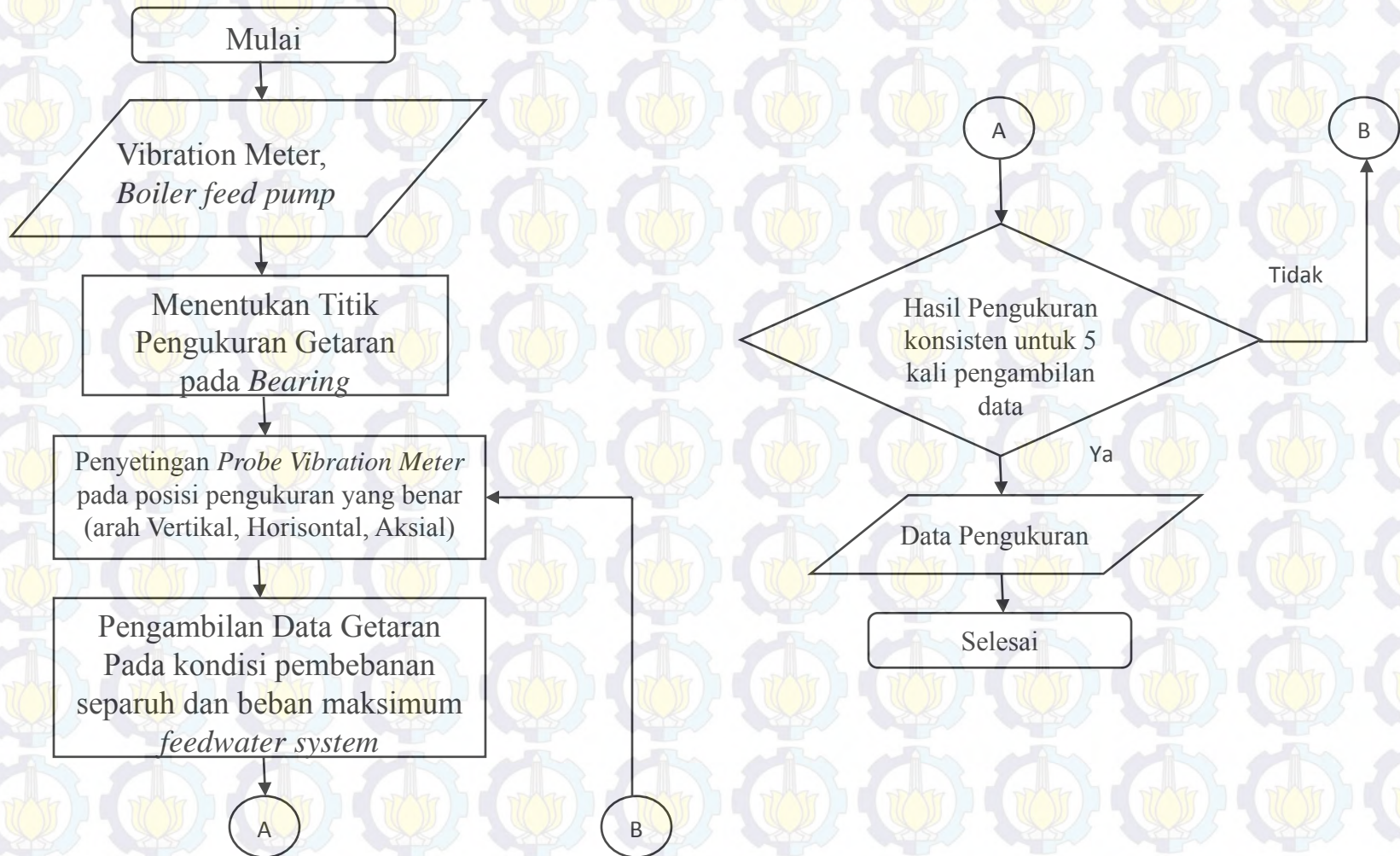


R.m.s vibration velocity mm/s	Class I	Class II	Class III	Class IV
0.28	A	A	A	A
0.45				
0.71				
1.12	B	B	B	B
1.8				
2.8	C	C	C	C
4.5				
7.1	D	D	D	D
11.2				
18				
28				
45				

**Figure 4.2** Table B.1 from ISO 10816-1 [6] giving recommended vibration limits for rotating machines in different classes. Class I – small machines and components (typ. <15 kW). Class II – medium machines without special foundations (typ. 15–75 kW). Class III – large machines on rigid and heavy foundations. Class IV – large machines on flexible foundations (typ. turbomachines). Zones: A, good; B, allowable; C, just tolerable; D, not permissible (Reproduced with permission from SAI Global under Licence 1008-c027. Available at <http://www.saiglobal.com>.).

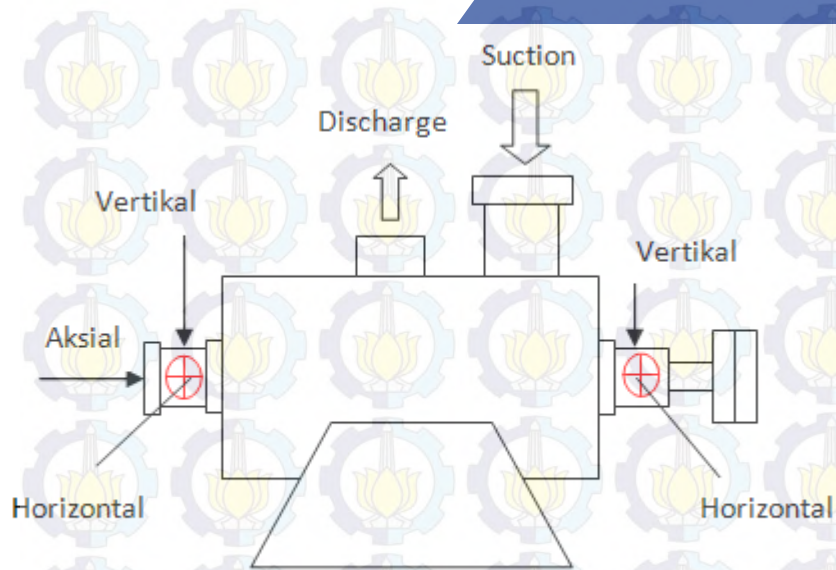




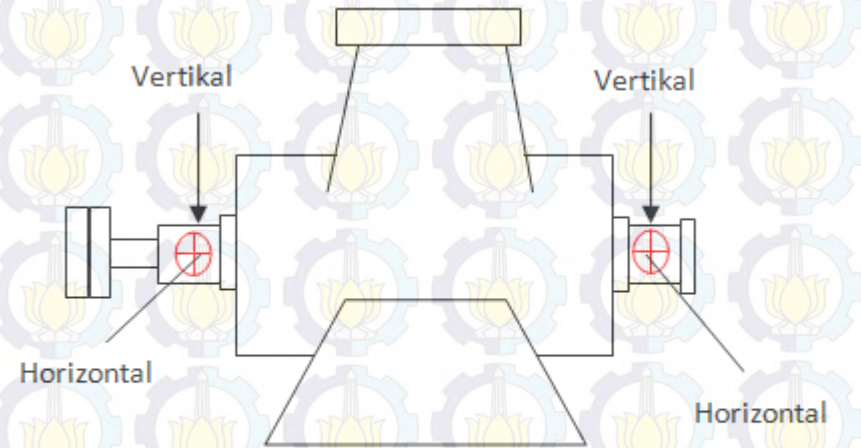




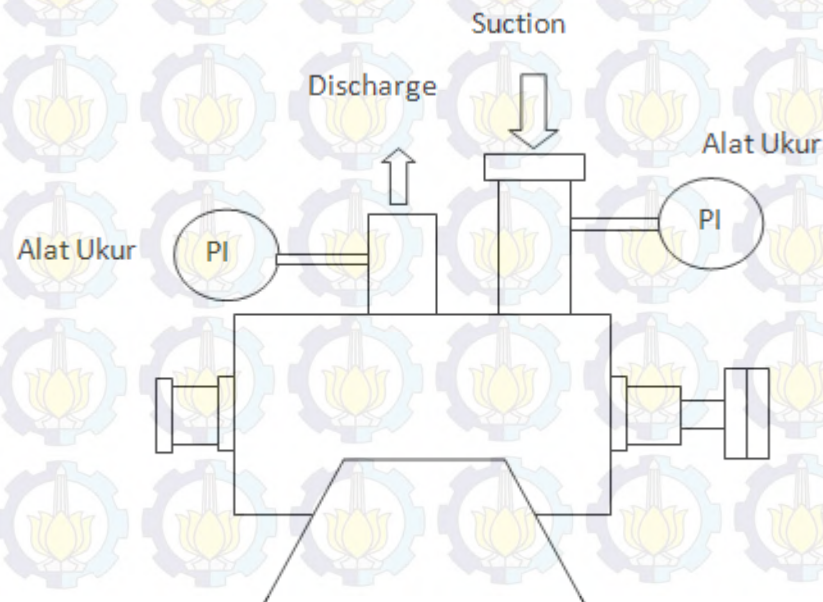
# Lokasi Pengukuran Vibrasi dan Tekanan



Gambar 3.2. Lokasi Pengukuran pada BFP

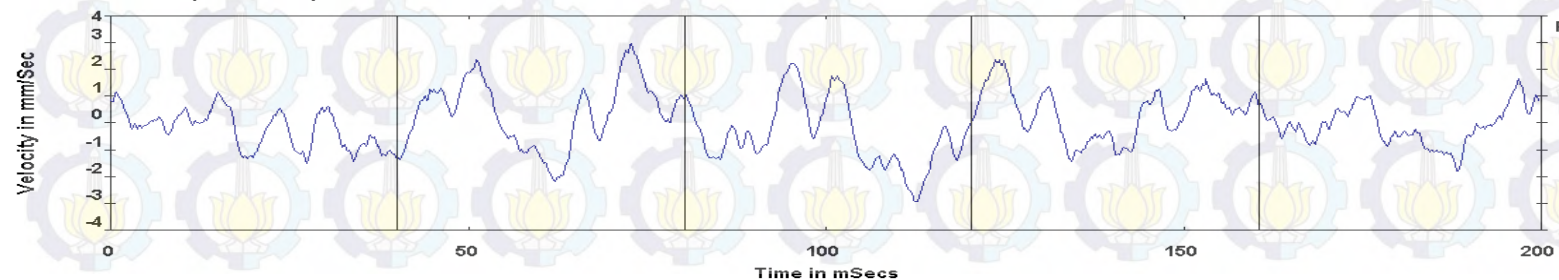
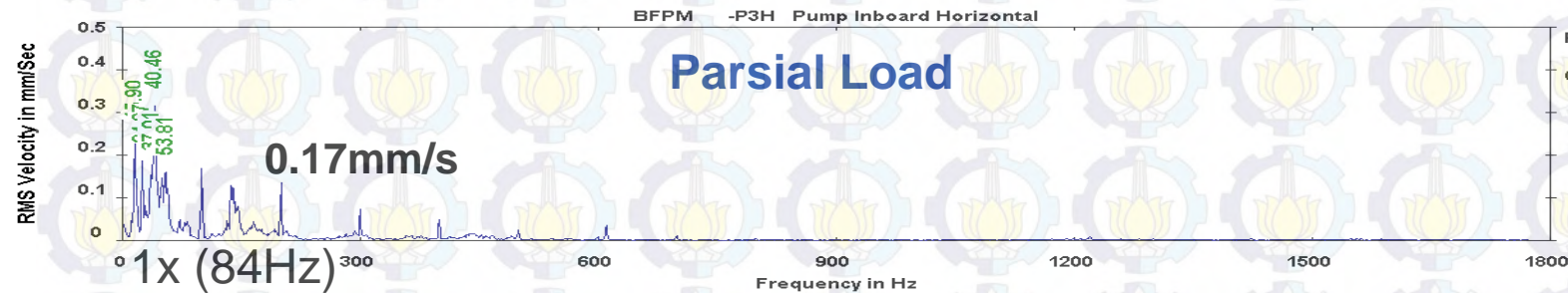
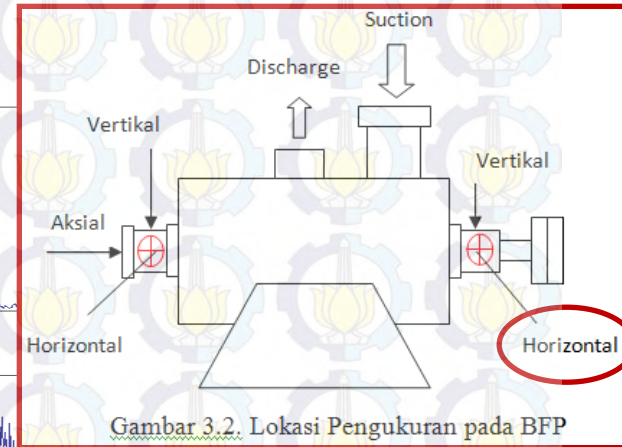
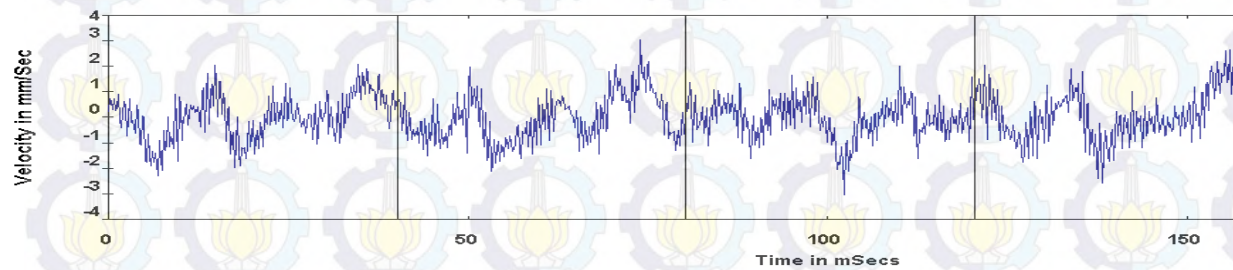
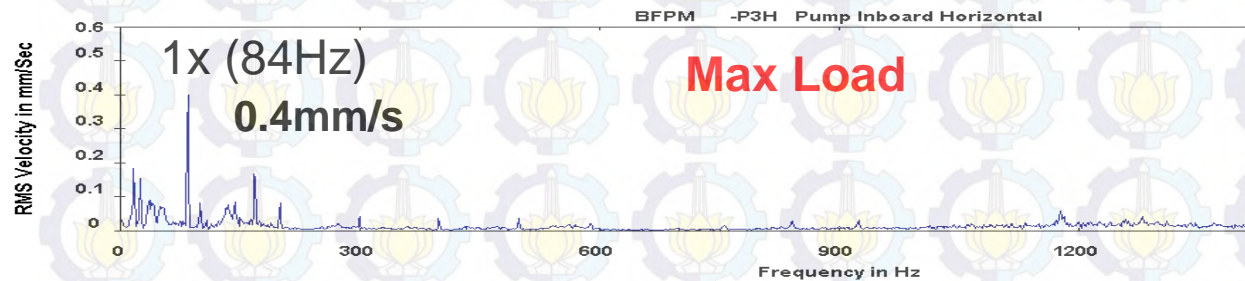


Gambar 3.3. Lokasi Pengukuran pada Booster Pump



Gambar 3.4. Lokasi Pengukuran Tekanan pada pompa

## BFPM Inboard Horizontal

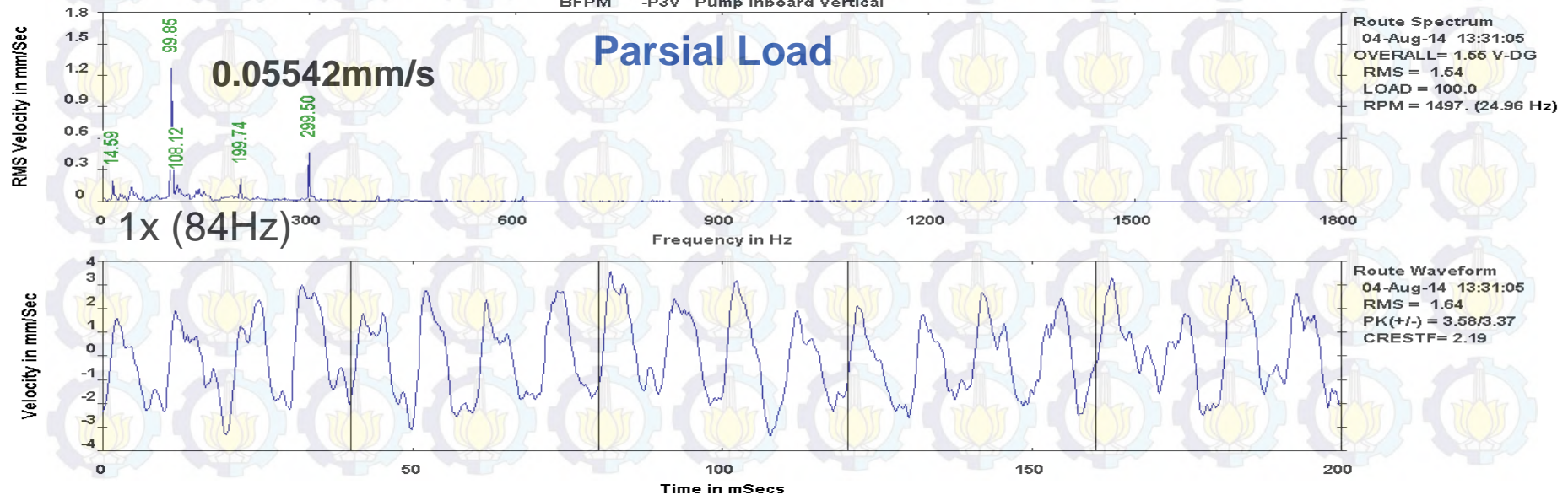
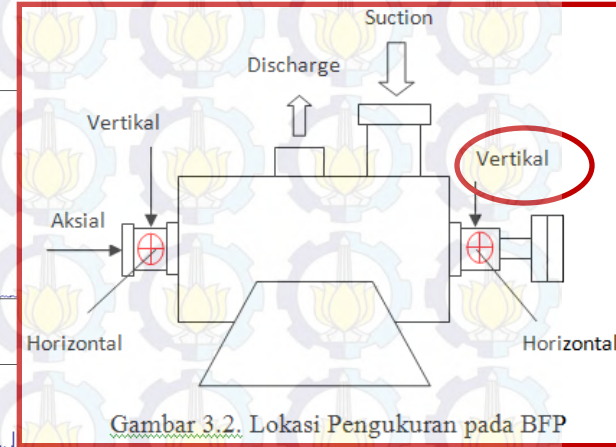
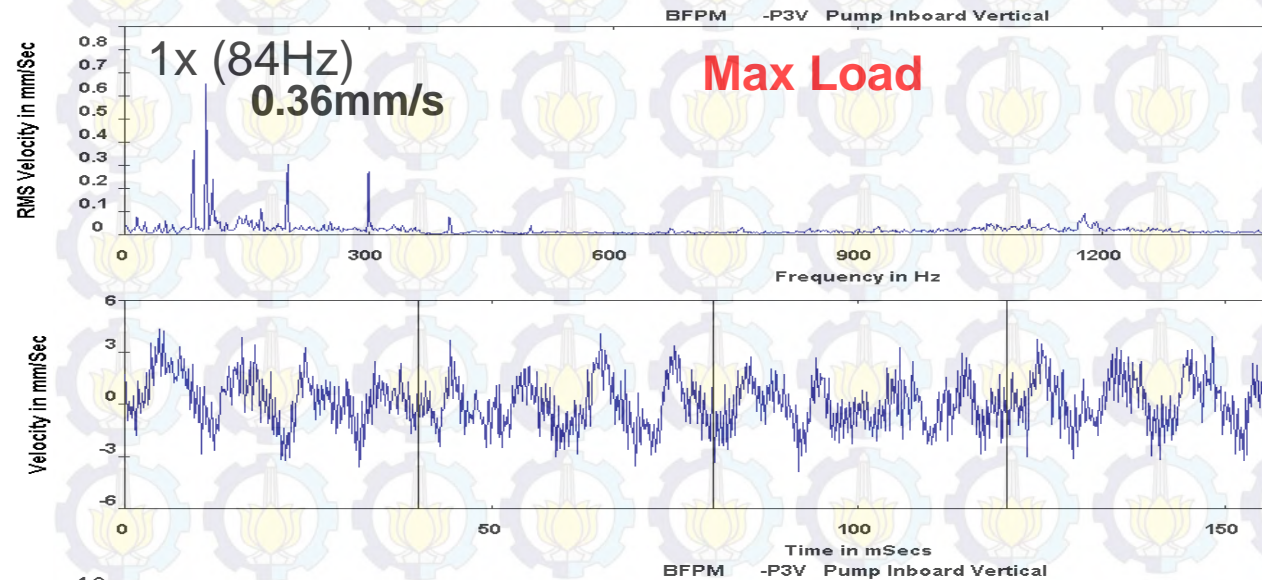


Route Spectrum  
04-Aug-14 13:30:50  
OVERALL= .8577 V-DG  
RMS = .8562  
LOAD = 100.0  
RPM = 1495. (24.92 Hz)

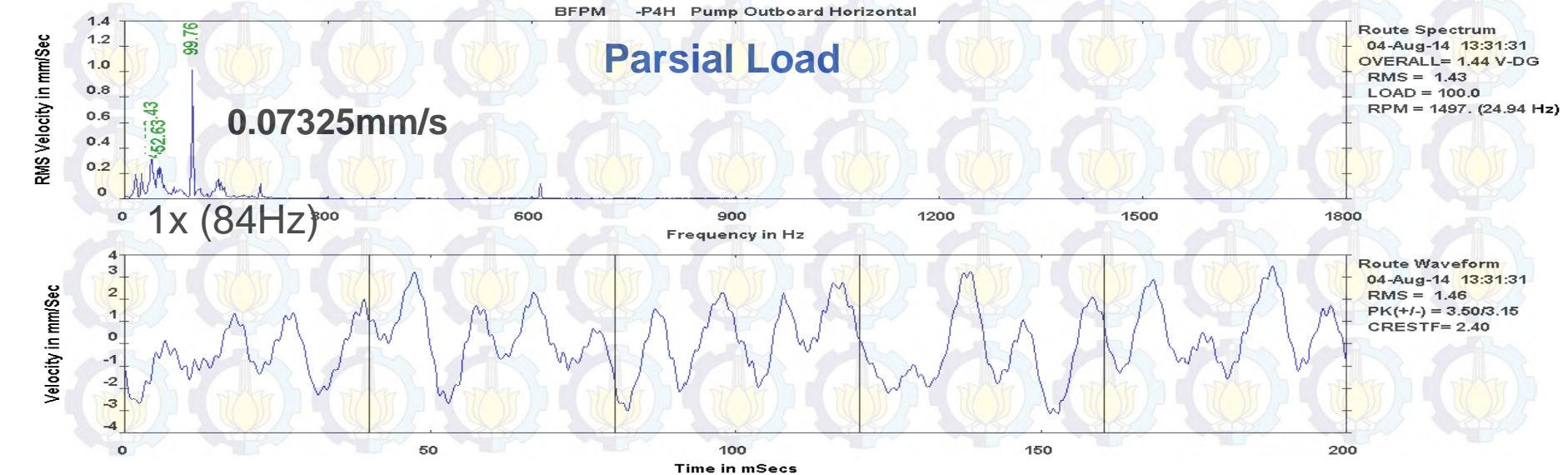
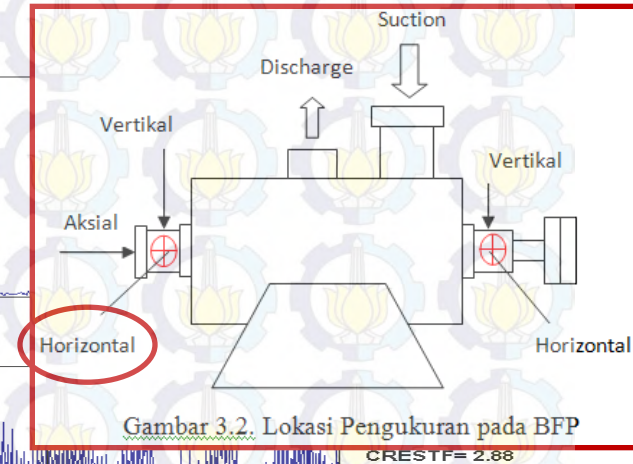
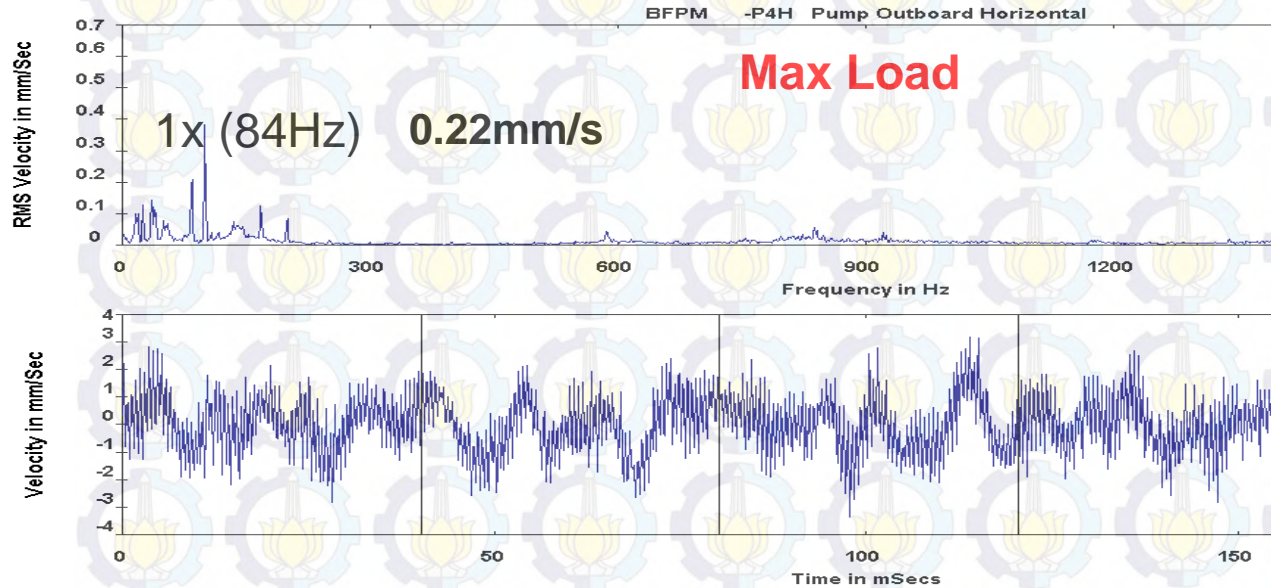
Route Waveform  
04-Aug-14 13:30:50  
RMS = 1.05  
PK(+/-) = 2.99/2.95  
CRESTF= 2.84



## BFPM Inboard vertikal

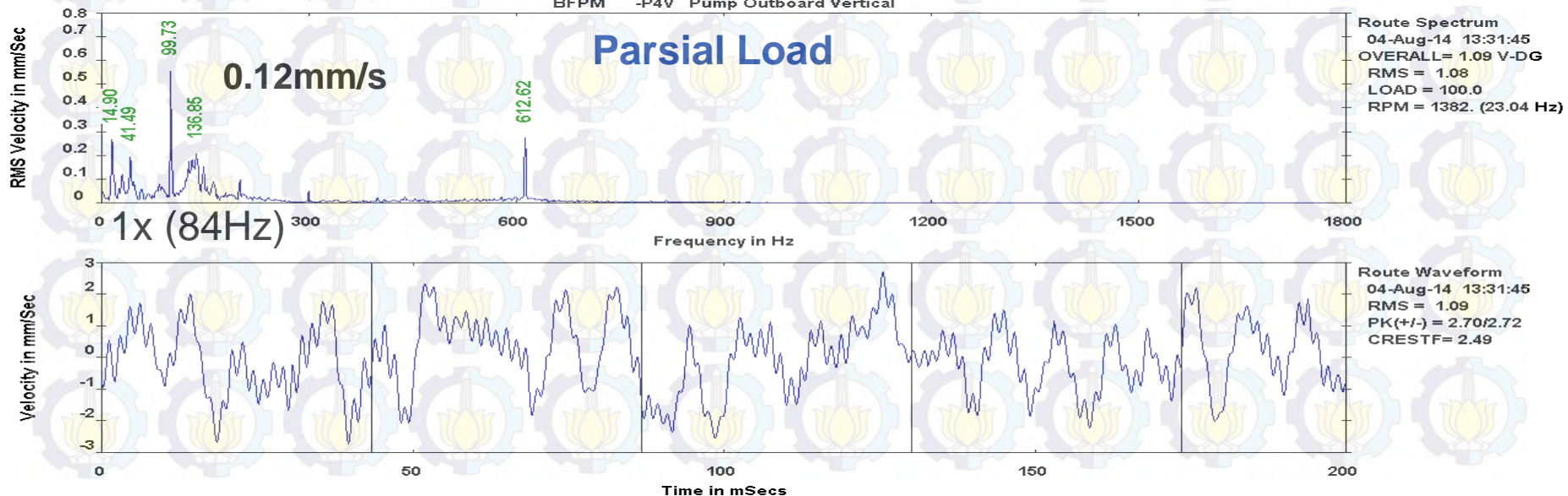
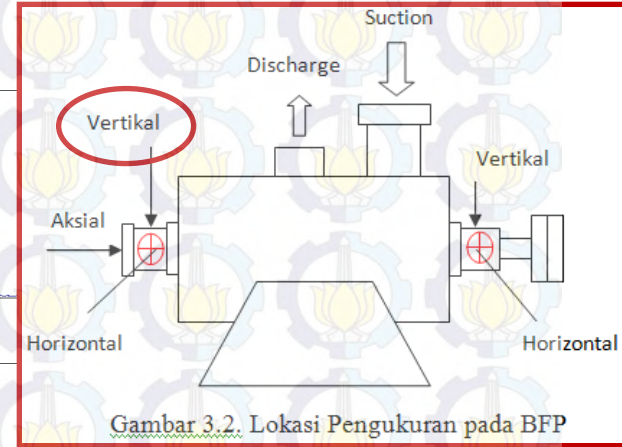
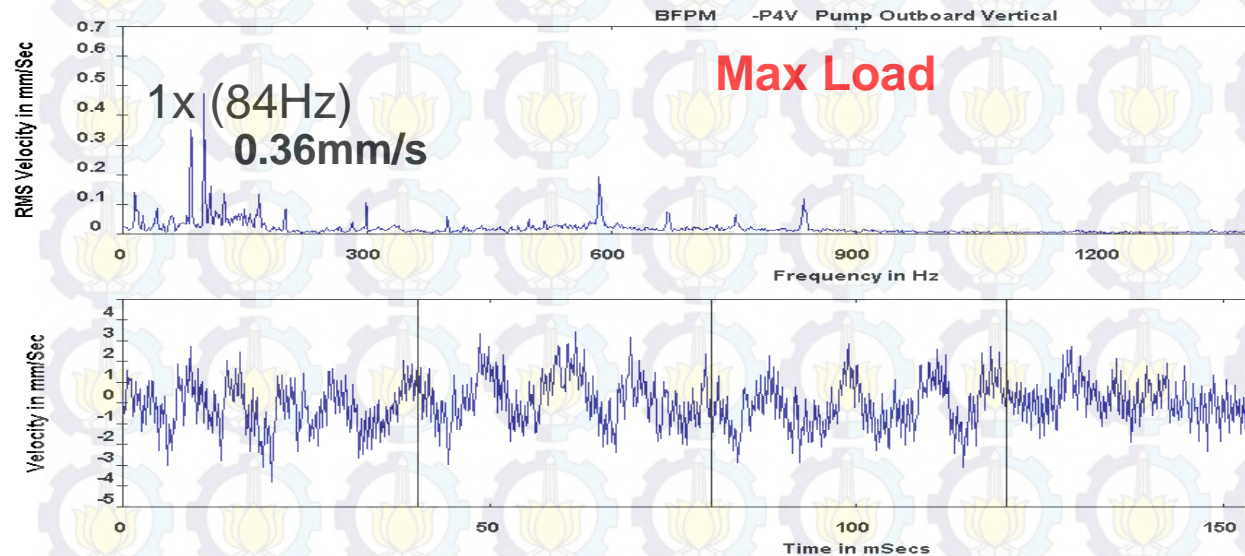


## BFPM Outboard Horizontal





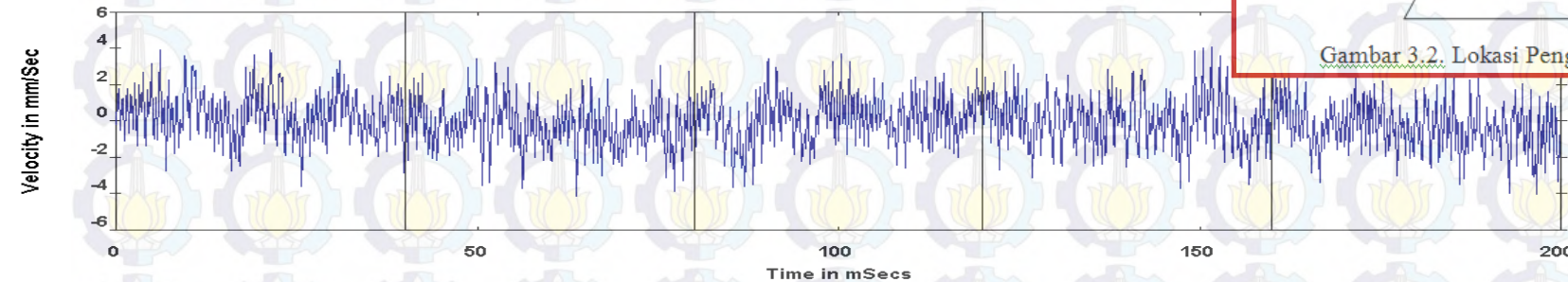
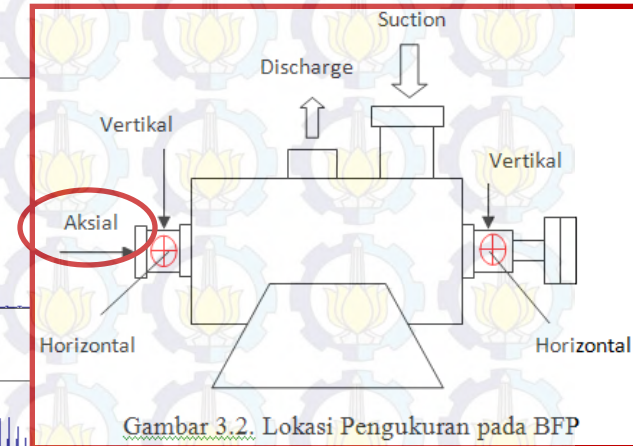
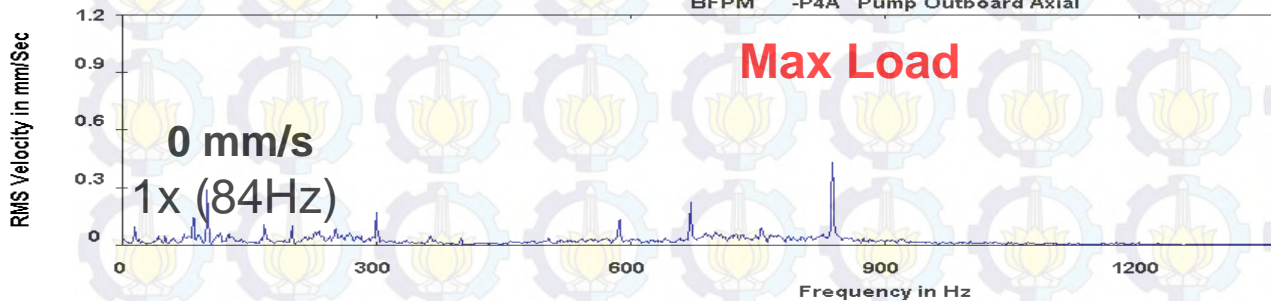
## BFPM Outboard Vertikal



## BFPM Outboard aksial

BFPM -P4A Pump Outboard Axial

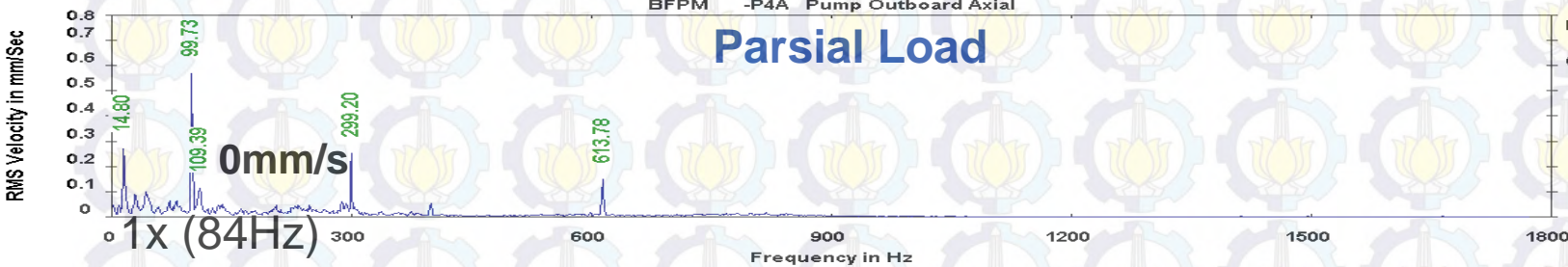
**Max Load**



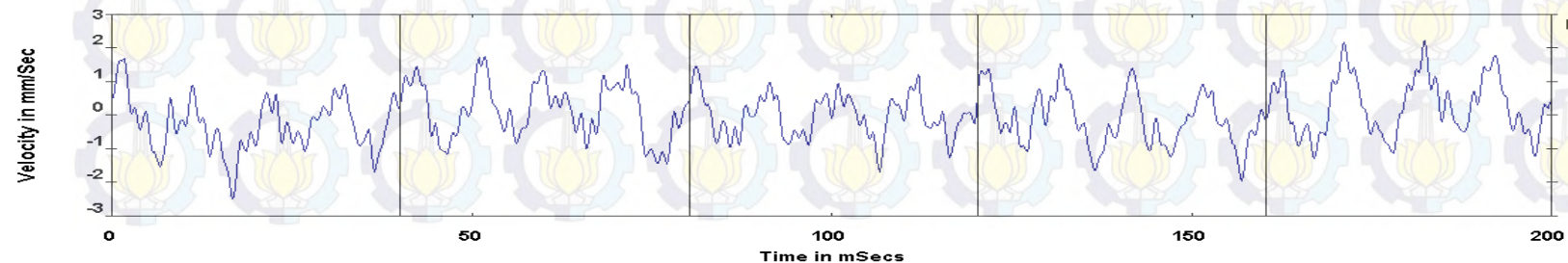
PK(+/-) = 4.06/4.12  
CRESTF = 2.70

BFPM -P4A Pump Outboard Axial

**Parsial Load**



Route Spectrum  
04-Aug-14 13:31:55  
OVERALL = .8982 V-DG  
RMS = .8951  
LOAD = 100.0  
RPM = 1497. (24.94 Hz)



Route Waveform  
04-Aug-14 13:31:55  
RMS = .7997  
PK(+/-) = 2.22/2.48  
CRESTF = 3.11



## 1.1mm/s Booster Pump outboard horizontal

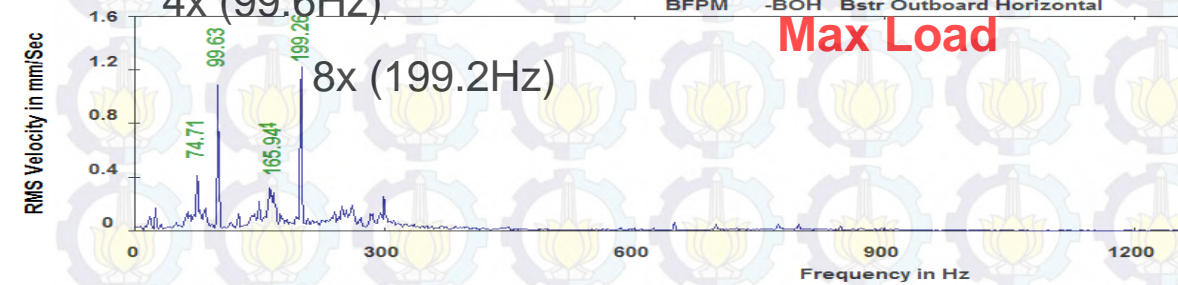
4x (99.6Hz)

8x (199.2Hz)

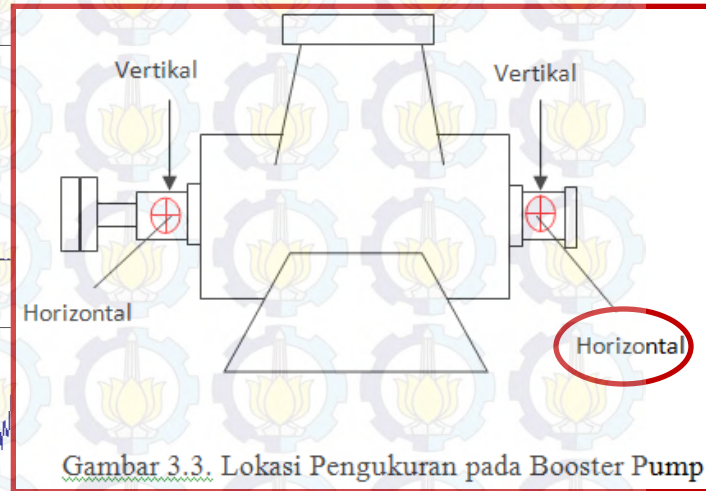
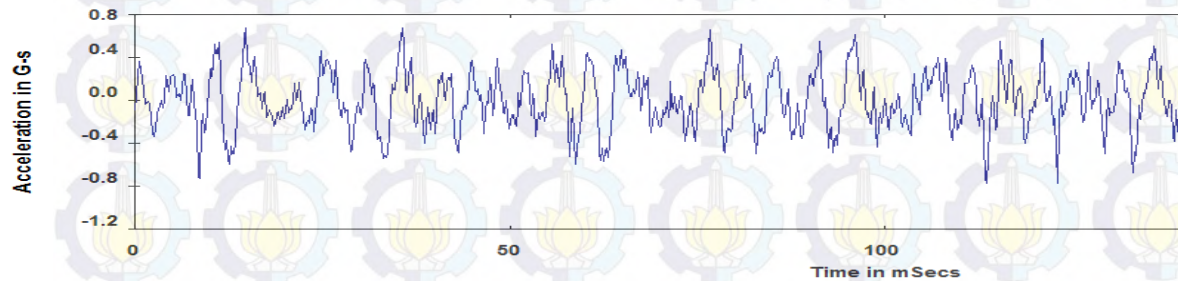
BFBM -BOH Bstr Outboard Horizontal

Max Load

RMS Velocity in mm/Sec



Acceleration in G-s



Gambar 3.3. Lokasi Pengukuran pada Booster Pump

2mm/s

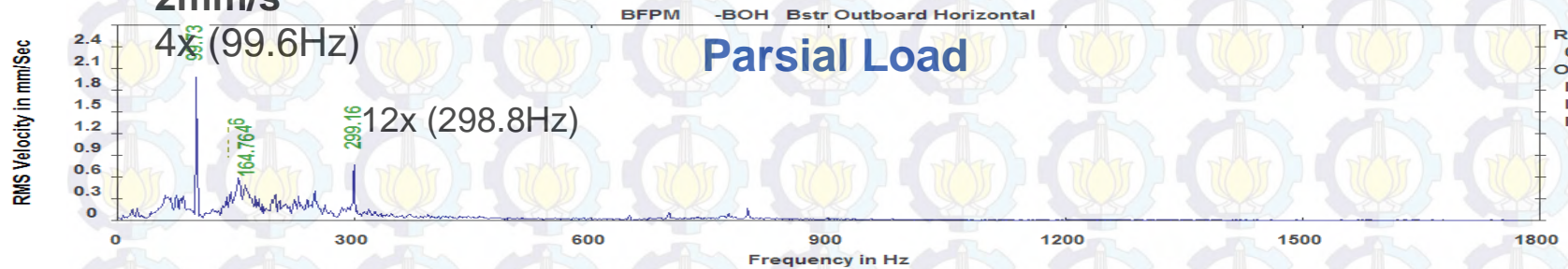
4x (99.6Hz)

12x (298.8Hz)

BFBM -BOH Bstr Outboard Horizontal

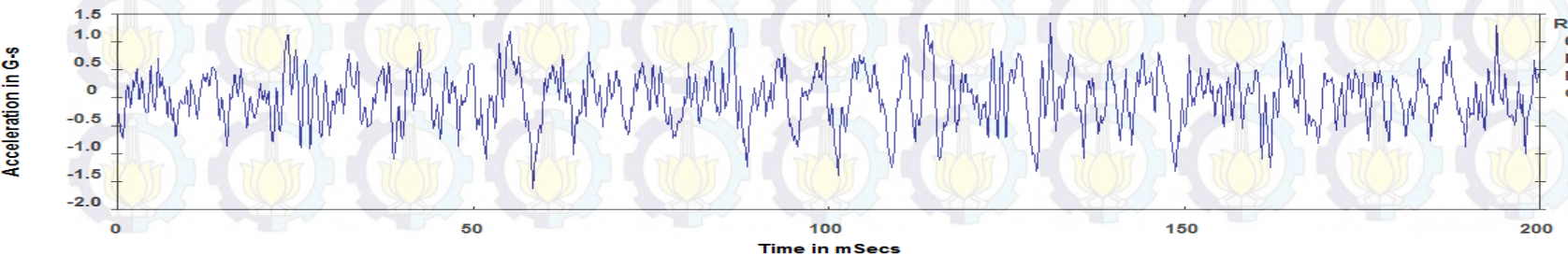
Parsial Load

RMS Velocity in mm/Sec



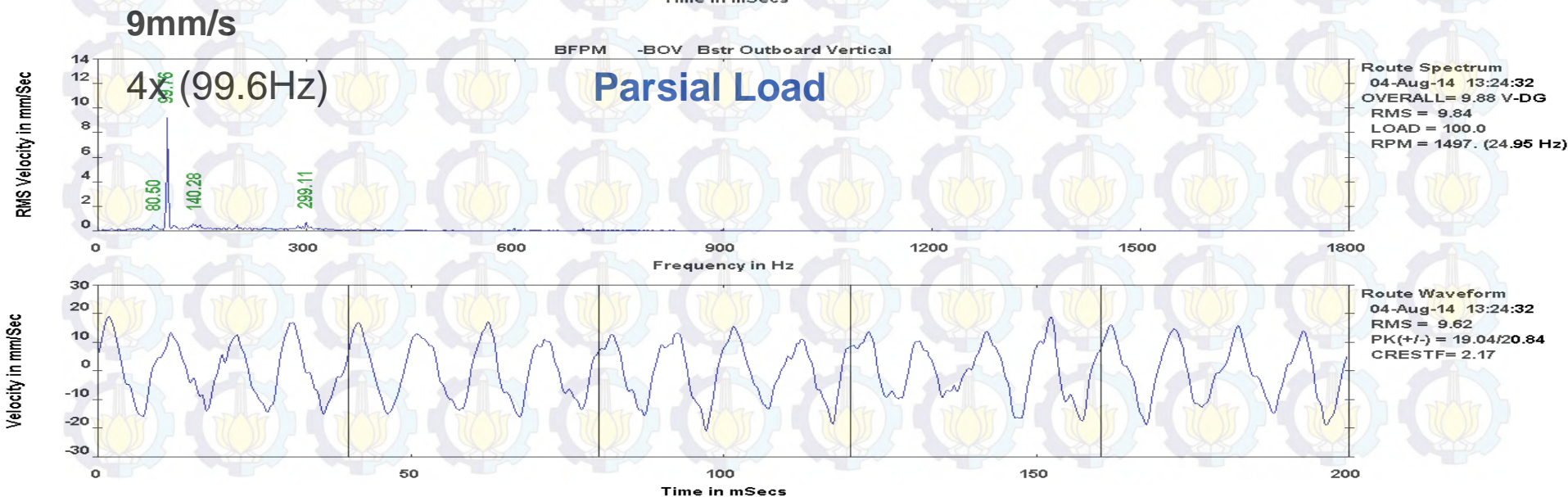
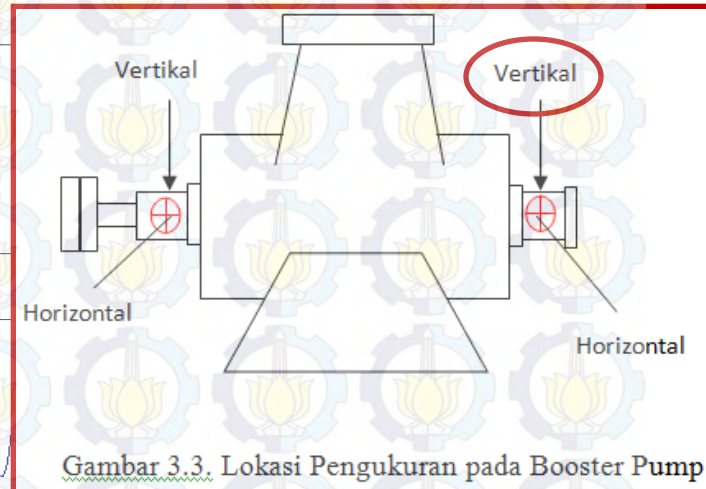
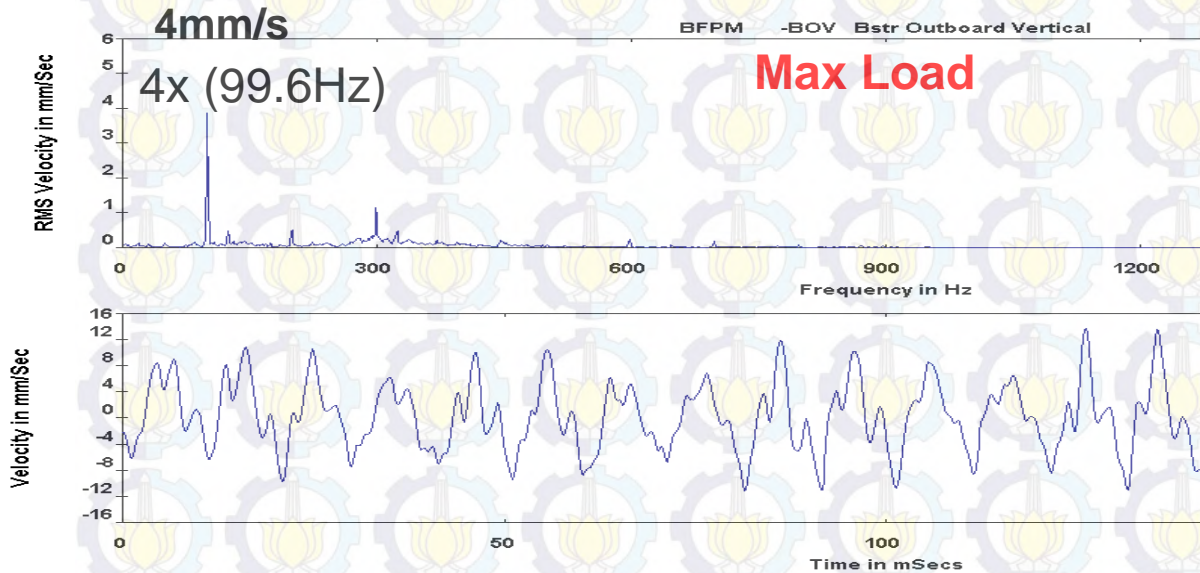
Route Spectrum  
04-Aug-14 13:24:19  
OVERALL= 3.65 V-DG  
RMS = 3.64  
LOAD = 100.0  
RPM = 1496. (24.93 Hz)

Acceleration in G-s



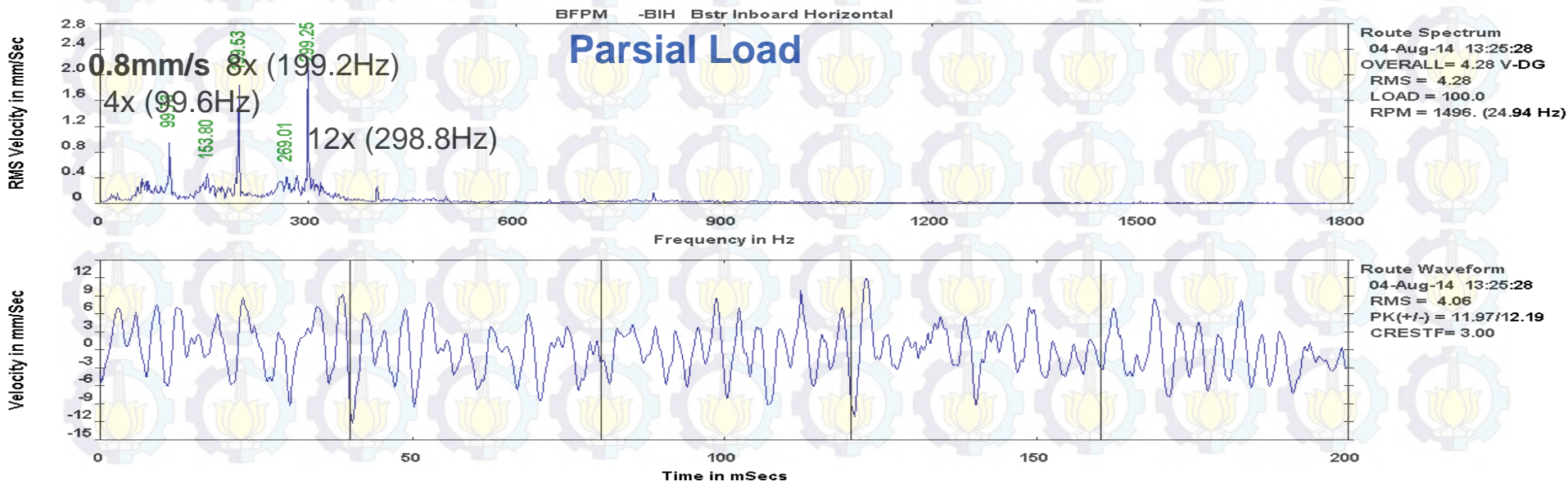
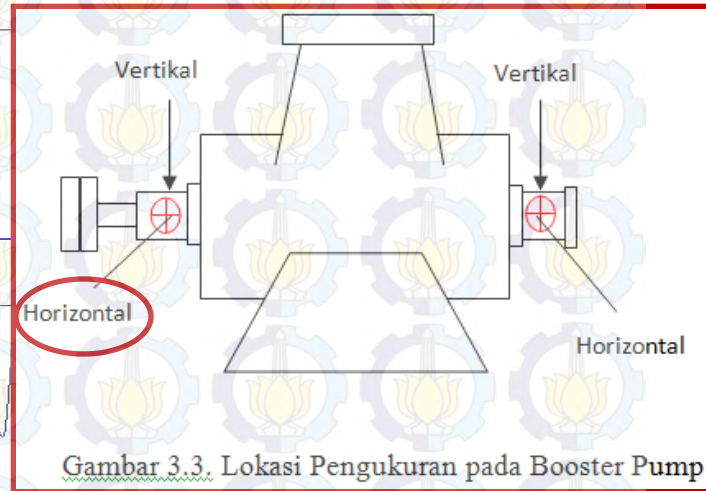
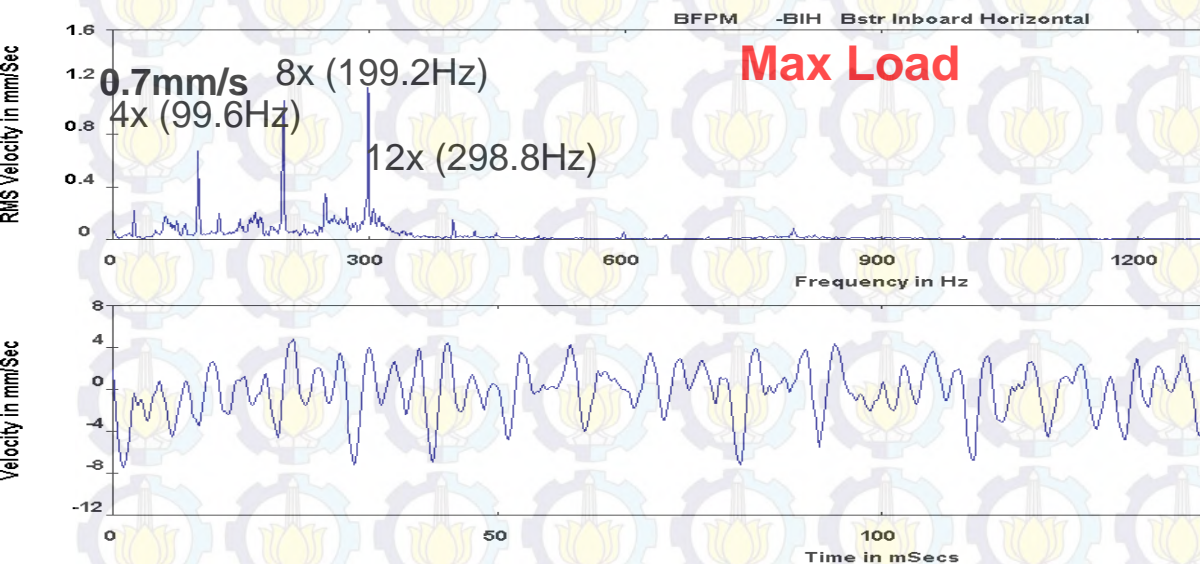
Route Waveform  
04-Aug-14 13:24:19  
RMS = .4779  
PK(+/-) = 1.35/1.63  
CRESTF= 3.40

## Booster Pump outboard vertikal

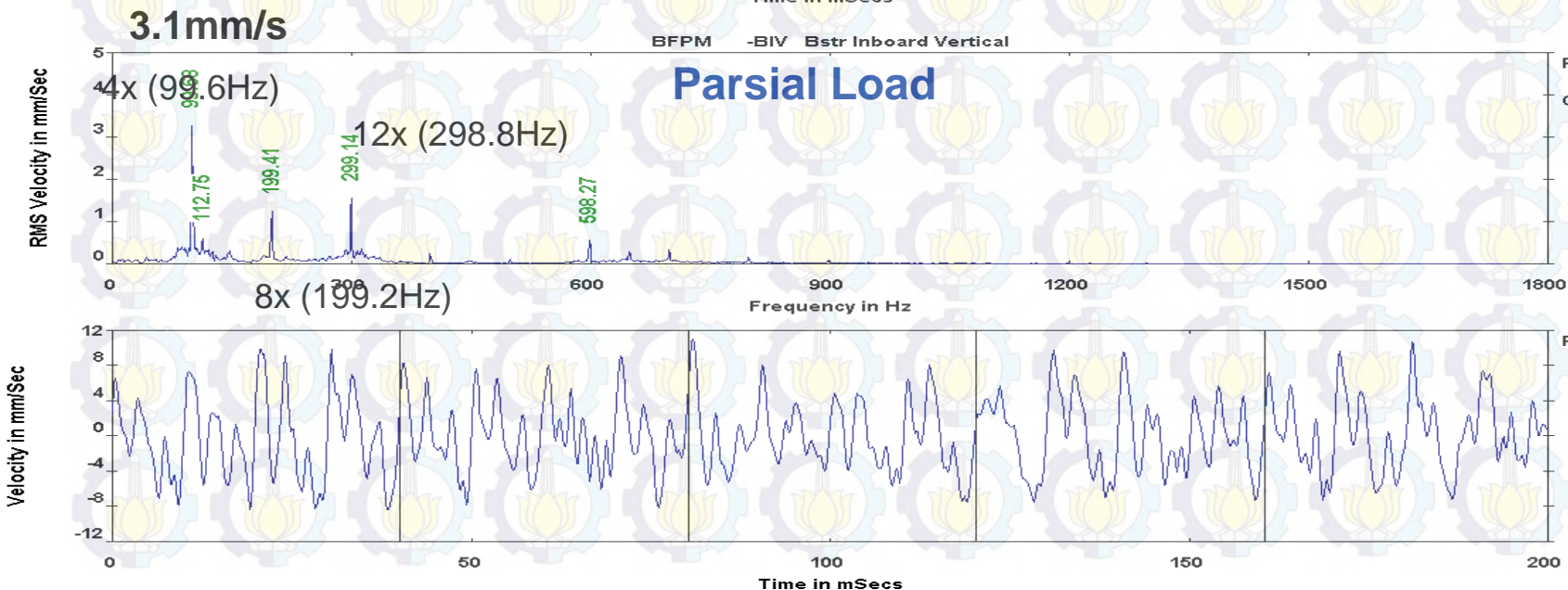
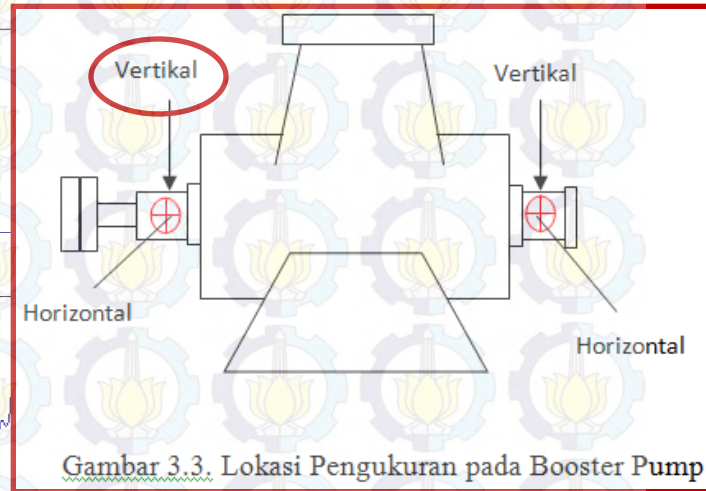
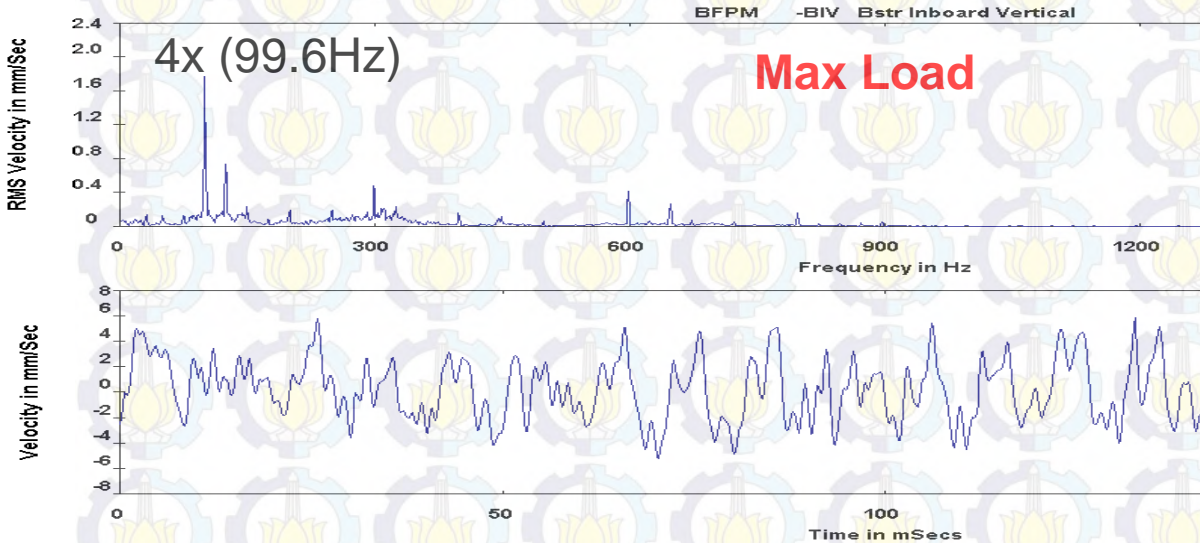




## Booster Pump inboard horizontal



## Booster Pump inboard vertikal



Route Spectrum  
04-Aug-14 13:25:55  
OVERALL= 4.81 V-DG  
RMS = 4.80  
LOAD = 100.0  
RPM = 1495. (24.92 H)

Route Waveform  
04-Aug-14 13:25:55  
RMS = 4.14  
PK(+/-) = 11.00/8.38  
CRESTF= 2.66

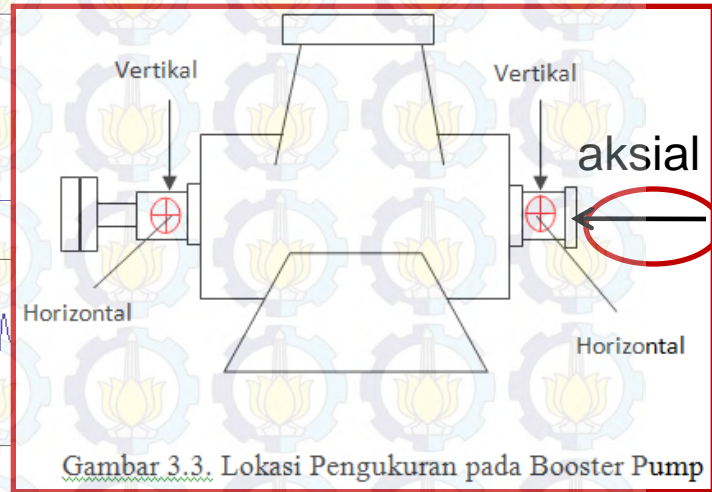
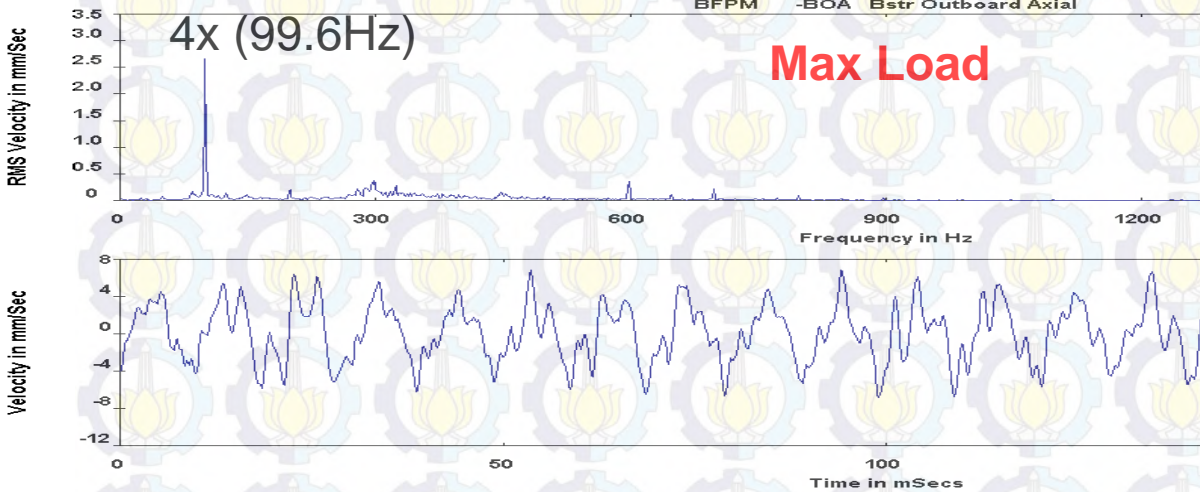


## Booster Pump outboard aksial

2.6mm/s

4x (99.6Hz)

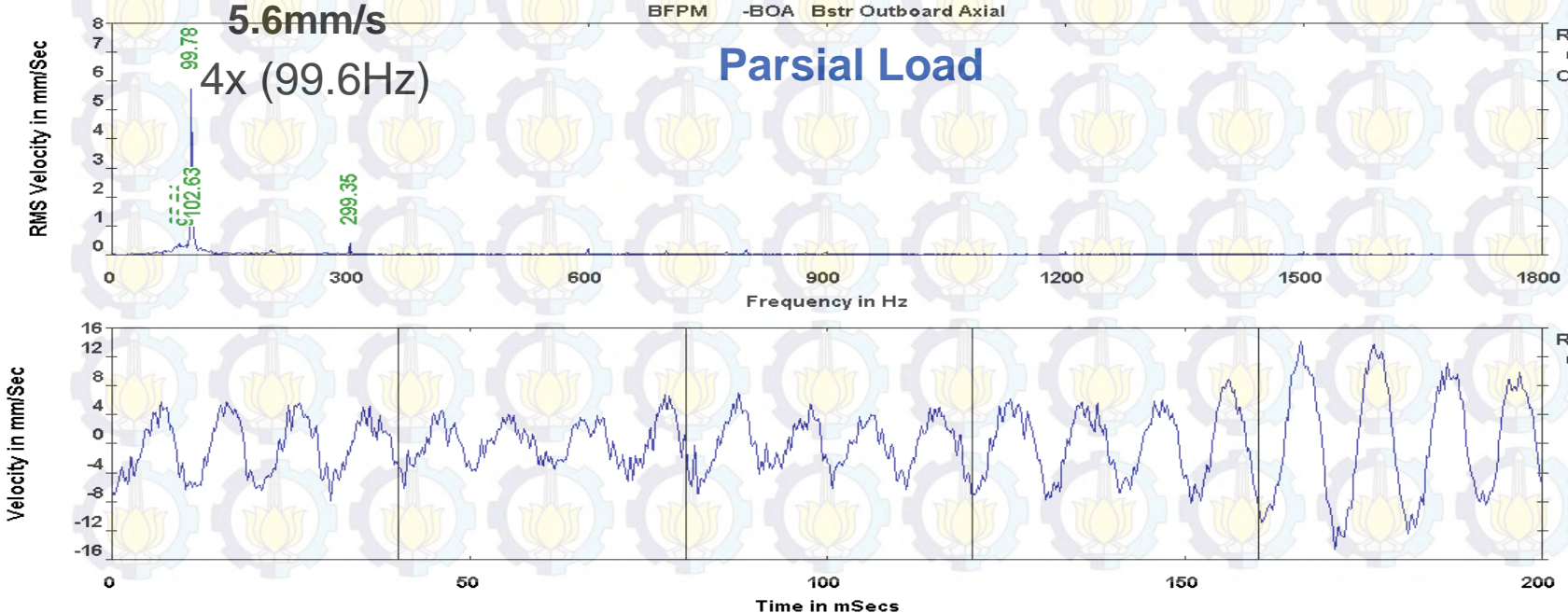
Max Load



Parsial Load

5.6mm/s

4x (99.6Hz)



Route Spectrum  
04-Aug-14 13:25:01  
OVERALL= 6.12 V-DG  
RMS = 6.12  
LOAD = 100.0  
RPM = 1497. (24.95 Hz)

Route Waveform  
04-Aug-14 13:25:01  
RMS = 4.94  
PK(+/-) = 14.18/14.57  
CRESTF= 2.95

# RMS Velocity BFPM & Booster Pump

			Parsial Load		Maksimum Load	
			Frekuensi	Velocity (mm/s)	Frekuensi	Velocity (mm/s)
BFPM	Outboard	Horizontal	1x (28.58 Hz)	0.1	1x (84.7 Hz)	0.37
		Vertikal	1x (28.58 Hz)	0.1	1x (84.7 Hz)	0.38
	Inboard	Horizontal	1x (28.58 Hz)	0.05	1x (84.7 Hz)	0.3
		Vertikal	1x (28.58 Hz)	0.06	1x (84.7 Hz)	0.37
Booster Pump	Outboard	Horizontal	4x (99.6 Hz)	1.9	4x (99.6 Hz)	1
		Vertikal	4x (99.6 Hz)	8.5	4x (99.6 Hz)	3.8
	Inboard	Horizontal	4x (99.6 Hz)	0.75	4x (99.6 Hz)	0.7
		Vertikal	4x (99.6 Hz)	3.05	4x (99.6 Hz)	1.65

BFPM : Dominan pada 1x putaran pada beban tinggi mengindikasikan hidraulik unbalance

Booster pump : Dominan pada 4x putaran mengindikasikan frequency blade pass







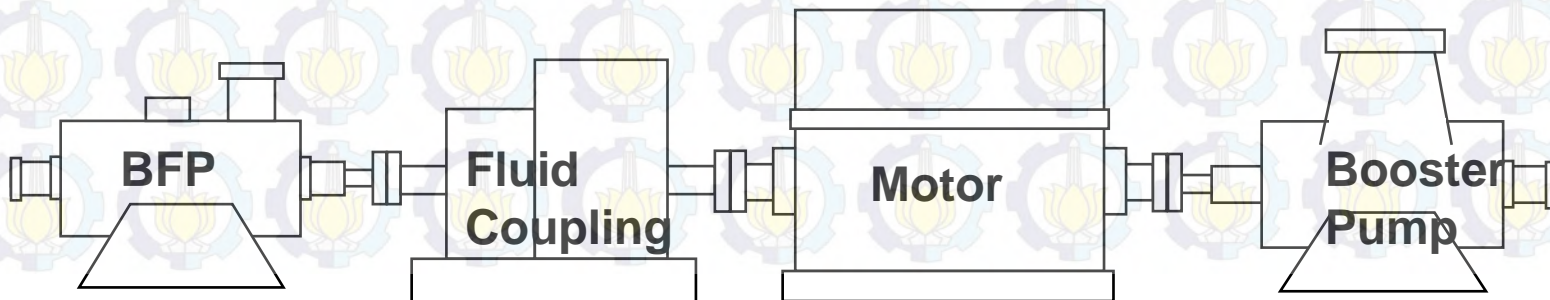
# Model Fisik Boiler Feed Pump



**Boiler Feed Pump**

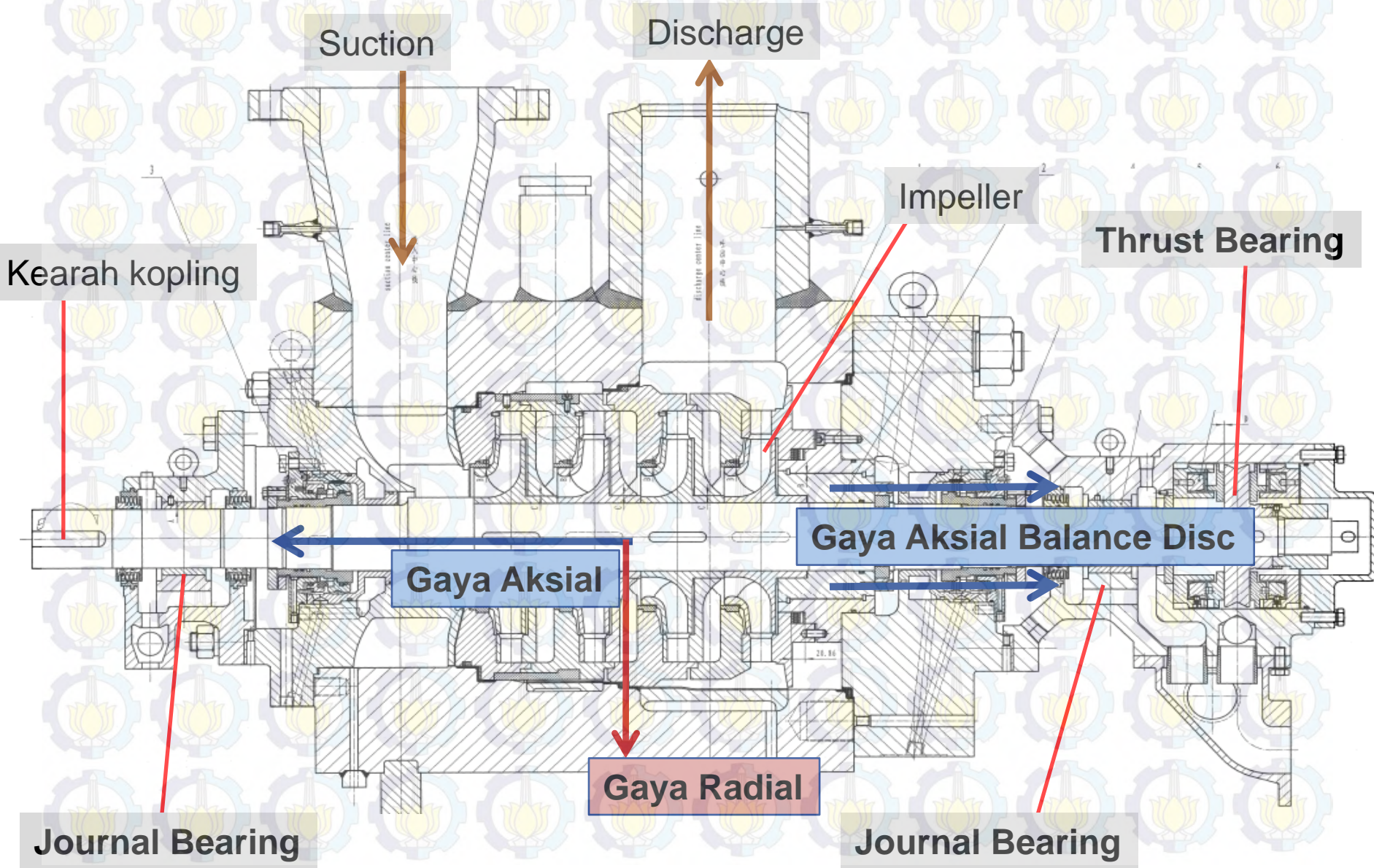
**Variable Speed Coupling**

**Booster Pump**



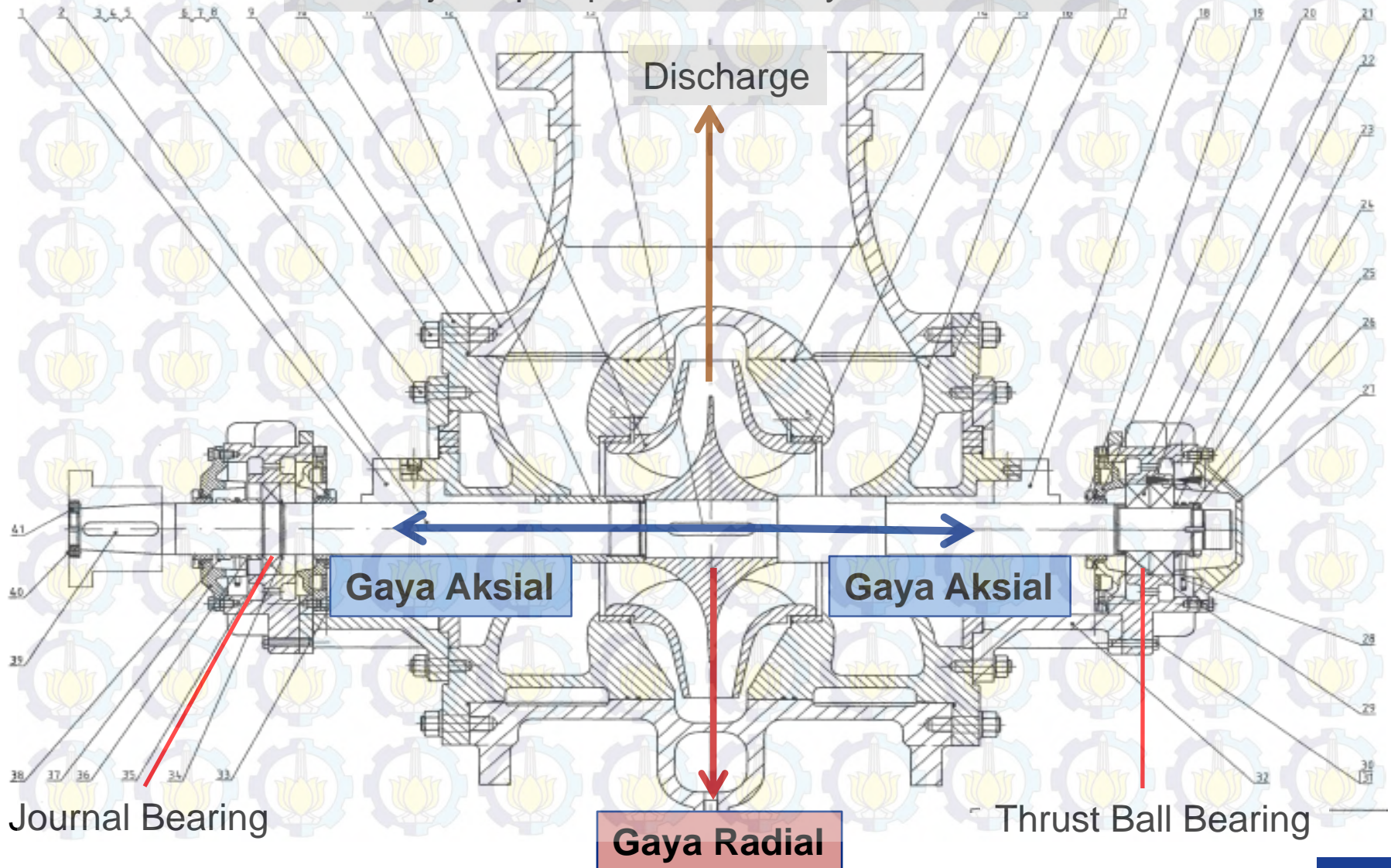


# Model Fisik Boiler Feed Pump





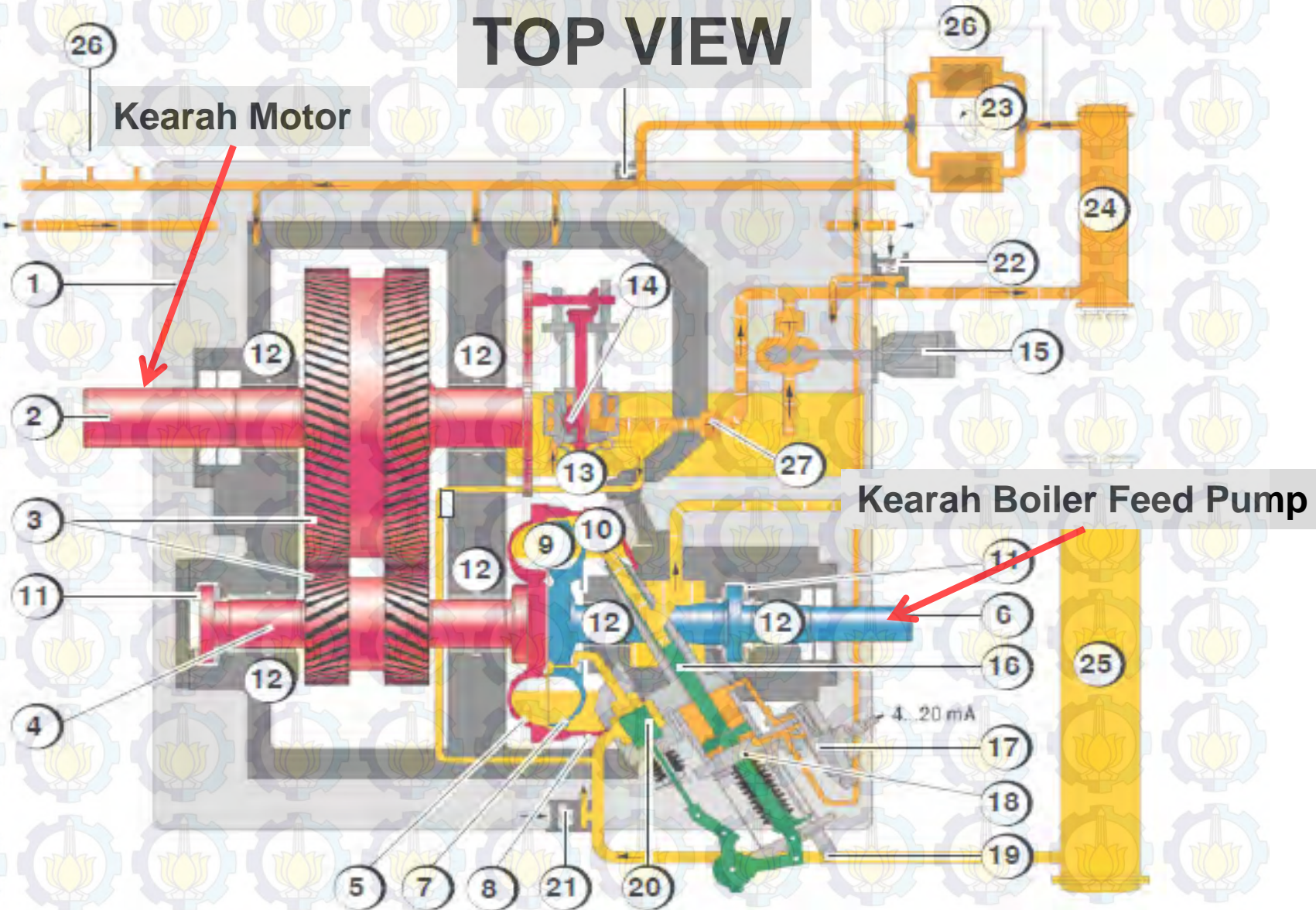
Gaya aksial pada booster pump dapat diabaikan  
Karena jenis pompa double entry



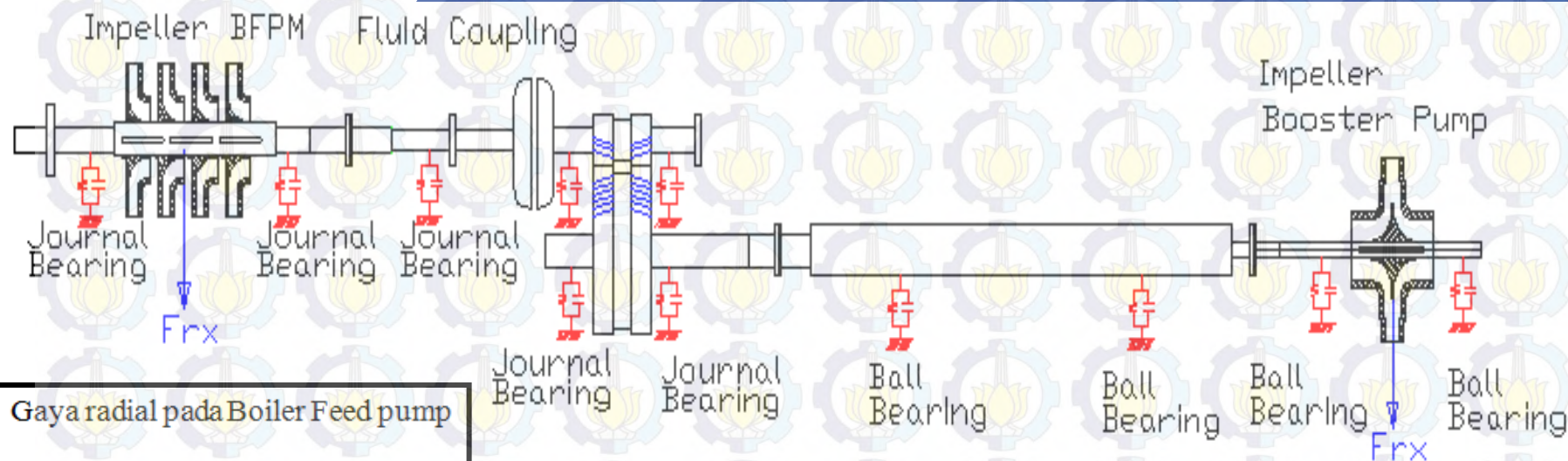


# Model Fisik Variable Speed Coupling

## TOP VIEW





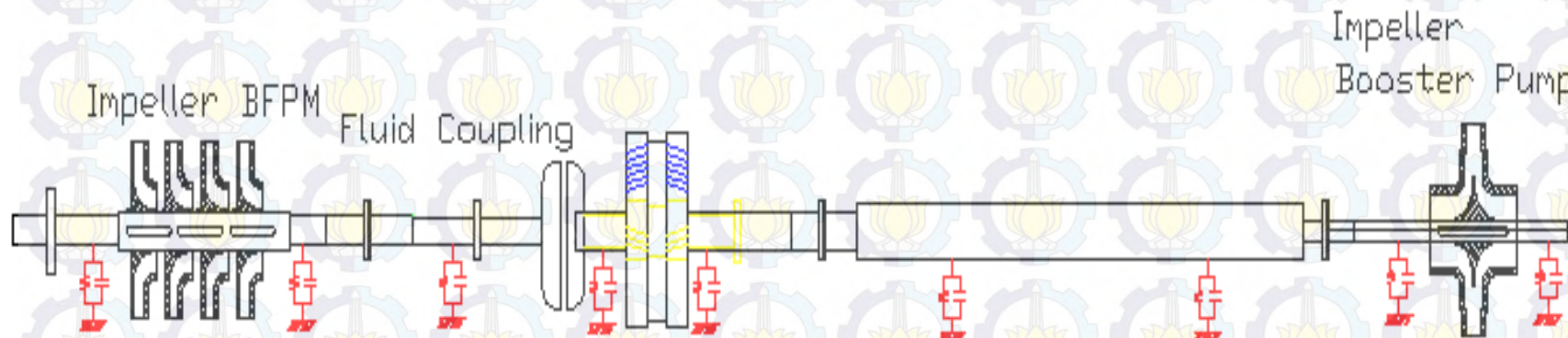


Gaya radial pada Boiler Feed pump

$$F_{rx} = K_{hu} \rho g H d_2 b_2 \sin(\omega t)$$

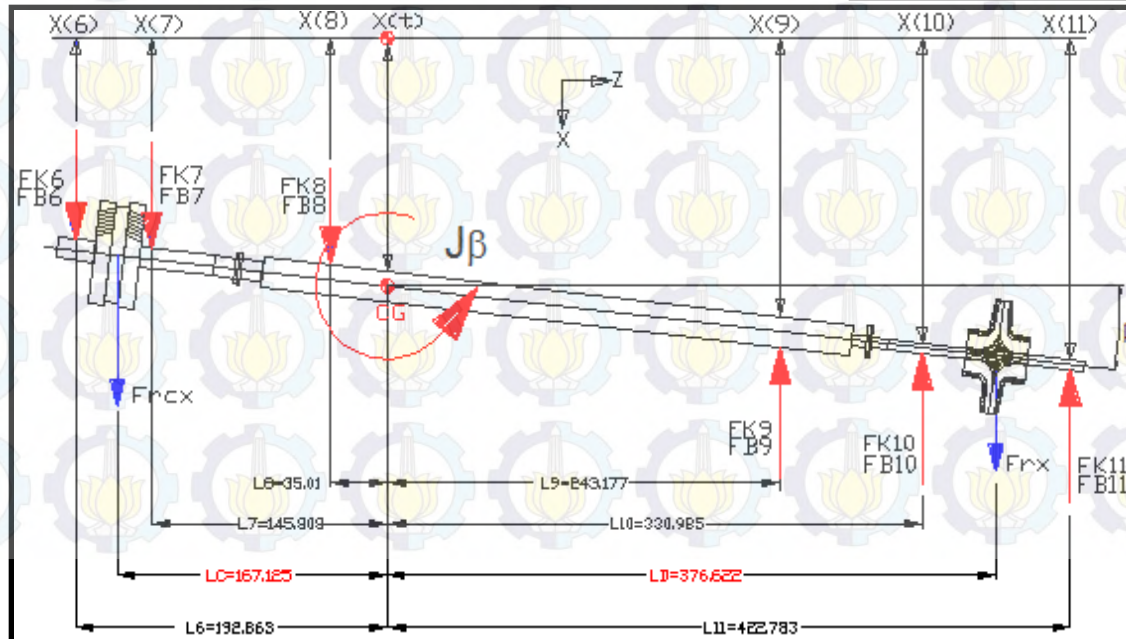
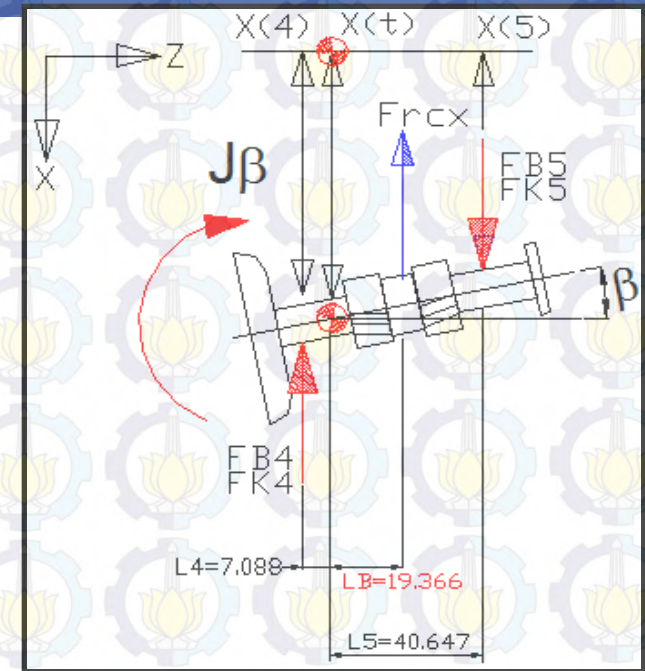
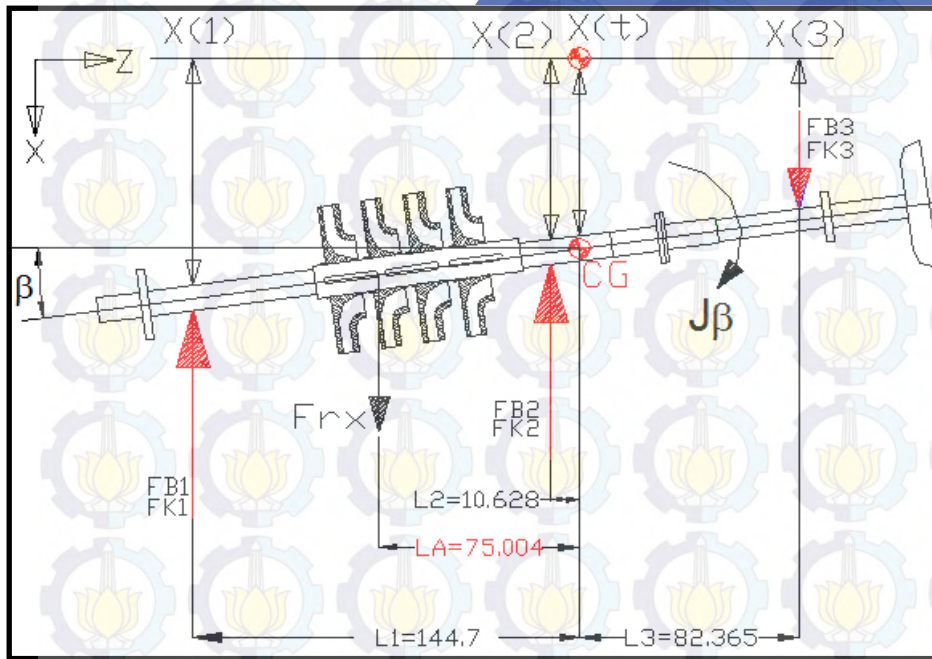
Gaya radial pada booster pump

$$F_{rx} = K_{hu} \rho g H d_2 b_2 \sin(\omega t)$$





# Free Body Diagram (Top View)







## BOOSTER





## BFPM

Model Parameter	Symbol	Nilai Parameter
Massa	M	424.573 Kg
Inersia	I	239011.923
Jarak Outboard JB thd CG	L1	1.447 m
Jarak Inboard JB thd CG	L2	0.10628 m
Jarak JB FC thd CG	L3	0.82365 m
Jarak Fr thd CG	LA	0.75004 m
Kekakuan Journal Brg BFP	K1	800,000,000 N/m
Kekakuan Journal Brg BFP	K2	800,000,000 N/m
Kekakuan Journal Brg FC	K3	800,000,000 N/m
Damping Coef Journal Brg	B1	10,000 Ns/m
Damping Coef Journal Brg	B2	10,000 Ns/m
Damping Coef Journal Brg	B3	10,000 Ns/m

## Pinion

Model Parameter	Symbol	Nilai Parameter
Massa	m	201.587 Kg
Inersia	I	2912.3034
Jarak JB FC thd CG	L4	0.07088 m
Jarak JB FC thd CG	L5	0.40647 m
Jarak Gaya Kontak thd CG	LB	0.19366 m
Kekakuan Journal Brg	K4	800,000,000 N/m
Kekakuan Journal Brg	K5	800,000,000 N/m
Damping Coef Journal Brg	B4	10,000 Ns/m

## Booster

Model Parameter	Symbol	Nilai Parameter
Massa	M	1673.55 Kg
Inersia	I	1603170.448
Jarak JB Outboard thd CG	L6	1.9286 m
Jarak Gaya Kontak thd CG	L7	1.45808
Jarak JB Inboard thd CG	L8	0.3501 m
Jarak Ball Brg thd CG	L9	2.43177 m
Jarak Ball Brg thd CG	L10	3.30985 m
Jarak Ang Ball Brg Inboard thd CG	L11	4.22783 m
Jarak Gaya Radial thd CG	LC	1.67125 m
Jarak Ang Ball Brg Outboard thd CG	LD	3.76622 m
Kekakuan Journal Brg	K6	800,000,000 N/m
Kekakuan Journal Brg	K7	800,000,000 N/m
Kekakuan Ball Brg	K8	900,000,000 N/m
Kekakuan Ball Brg	K9	900,000,000 N/m
Kekakuan Ball Brg	K10	900,000,000 N/m
Kekakuan Ball Brg	K11	900,000,000 N/m
Damping Coef Journal Brg	B6	10,000 Ns/m
Damping Coef Journal Brg	B7	10,000 Ns/m
Damping Coef Ball Brg	B8	11,000 Ns/m
Damping Coef Ball Brg	B9	11,000 Ns/m
Damping Coef Ball Brg	B10	11,000 Ns/m
Damping Coef Ball Brg	B11	11,000 Ns/m



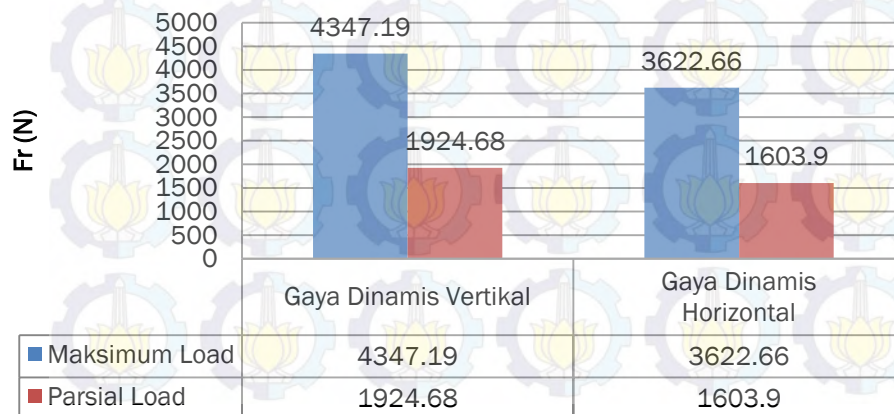
## BFPM

## Booster

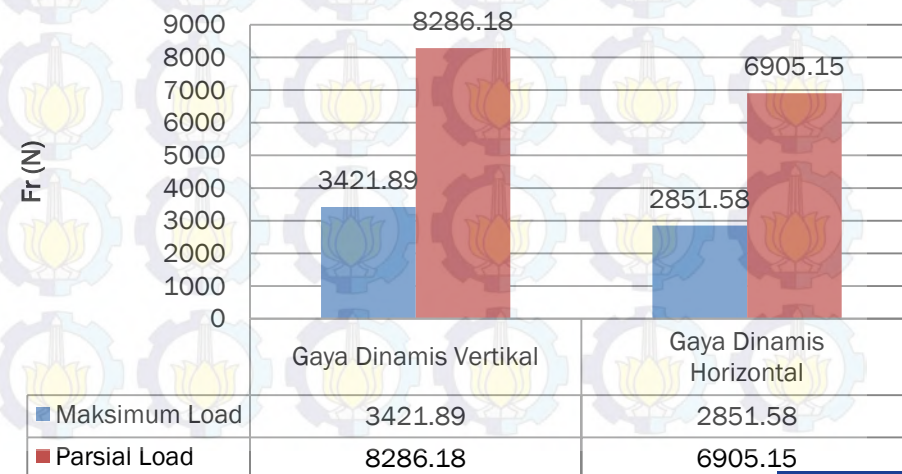
Parameter	Simbol	Nilai Parameter
Konstanta Hidrolik (Max/Min)	Kd	0.005 / 0.02
Density @153.1 bar; 138.9°C	$\rho$	931.13 Kg/m <sup>3</sup>
Density @100°C	P	960 Kg/m <sup>3</sup>
Gravitasi	G	9.8 m/s <sup>2</sup>
Diameter Impeler BFP	D2	0.31375 m
Lebar Shroud BFP	B2	0.0441 m
Jumlah Impeler BFP	-	4
Suction Pressure (Max/Min)	Psuct	12.69 / 14.646 bar
Discharge Pressure (Max/Min)	Pdisc	153.1 / 29.72 bar
Head	H	1434.62 m

Parameter	Simbol	Nilai Parameter
Konstanta Hidrolik (Max / Min)	Kd	0.1 / 0.2
Density @12.69 bar; 138.9°C	$\rho$	927.361 Kg/m <sup>3</sup>
Density @100°C	$\rho$	960 Kg/m <sup>3</sup>
Gravitasi	g	9.8 m/s <sup>2</sup>
Diameter Impeler Booster	D2	0.401333 m
Lebar Shroud Booster	B2	0.074667 m
Suction Pressure (Max/Min)	Psuct	2.442 / 2.66 bar
Discharge Pressure (Max/Min)	Pdisc	12.69 / 14.646 bar
Head (Max/Min)	H	104.71 / 122.47 m

### Gaya Dinamis BFPM



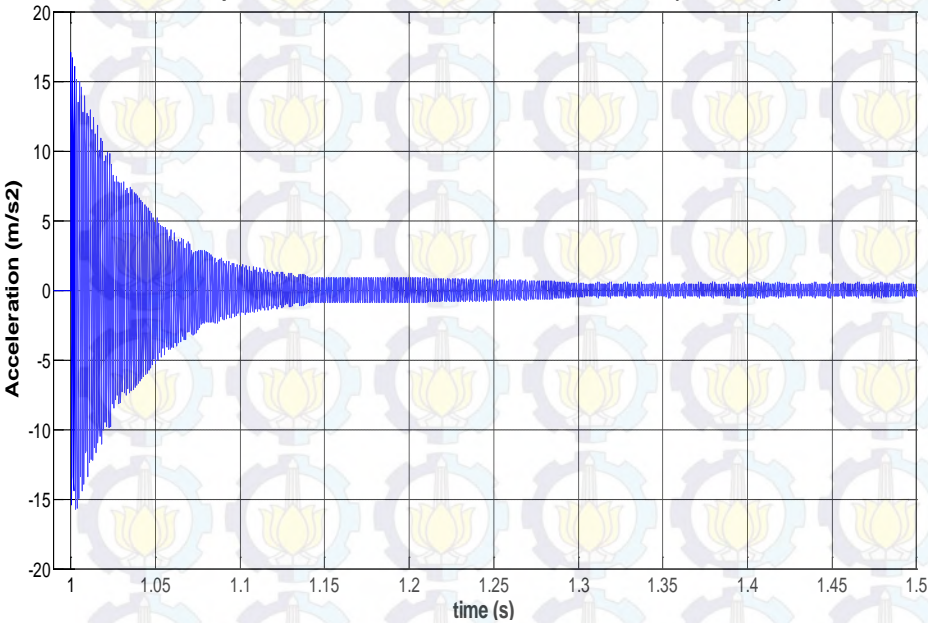
### Gaya Dinamis Booster Pump



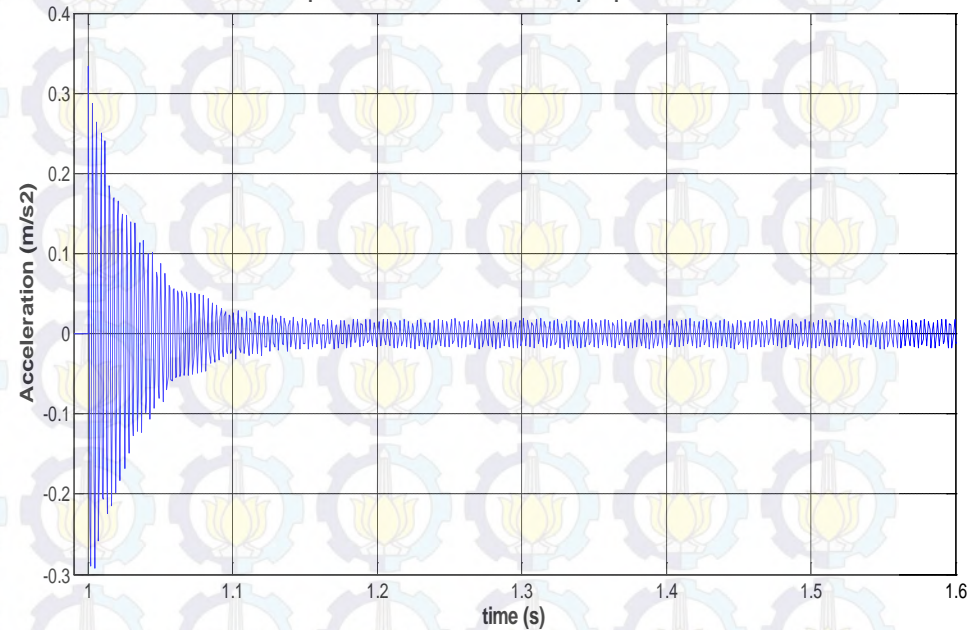


# Respon Transient

Respon Getaran Transient BFPM Acceleration X (Max Load)



Respon Getaran Transient Booster pump Acceleration X

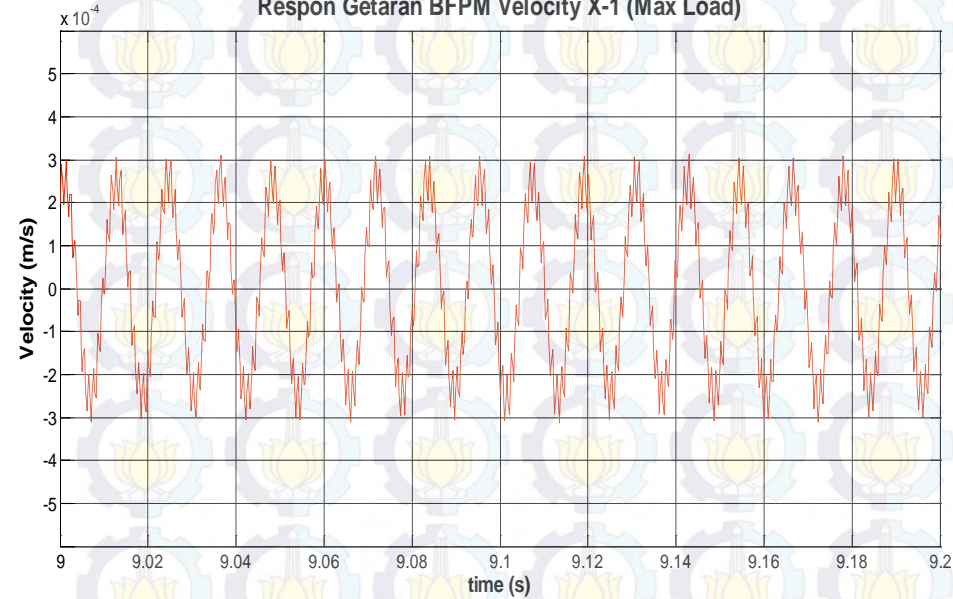


	Peak Amplitudo	Waktu Stabil
BFPM Max Load	16 m/s <sup>2</sup>	1.35 detik
Booster Max Load	0.3 m/s <sup>2</sup>	1.2 detik

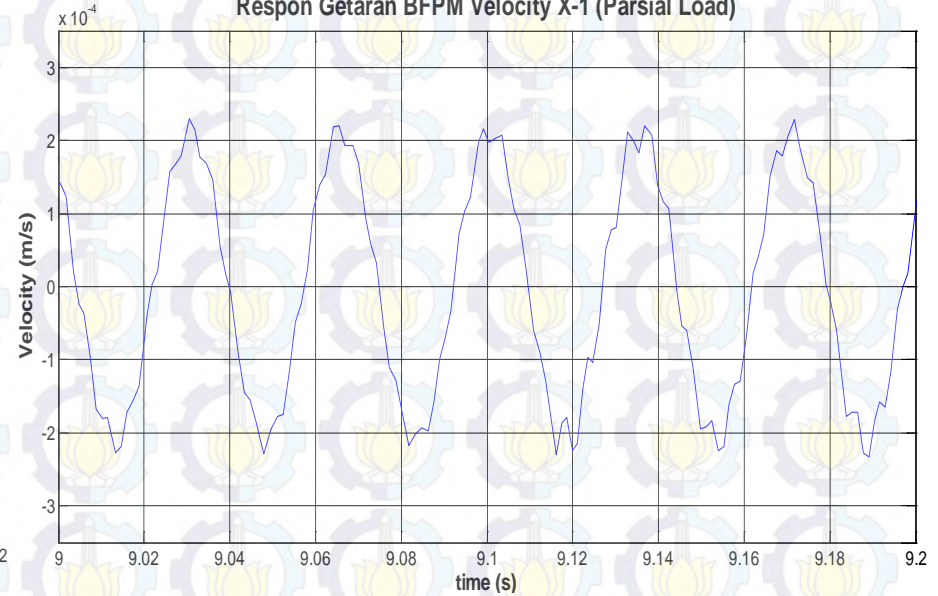


# Hasil Simulasi *Boiler Feed Pump*

Respon Getaran BFPM Velocity X-1 (Max Load)



Respon Getaran BFPM Velocity X-1 (Parsial Load)

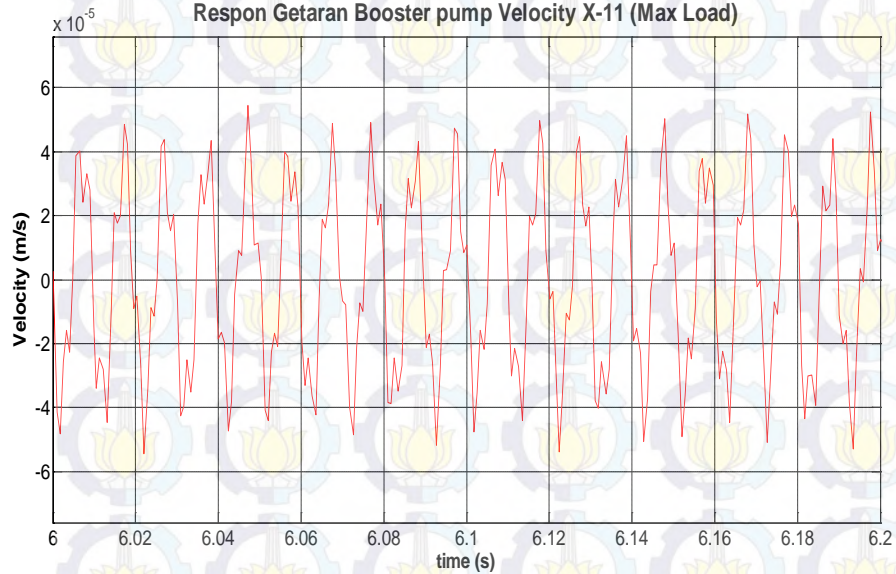


	Frekuensi
BFPM Max Load	84.7 Hz
BFPM Parsial Load	28.58 Hz

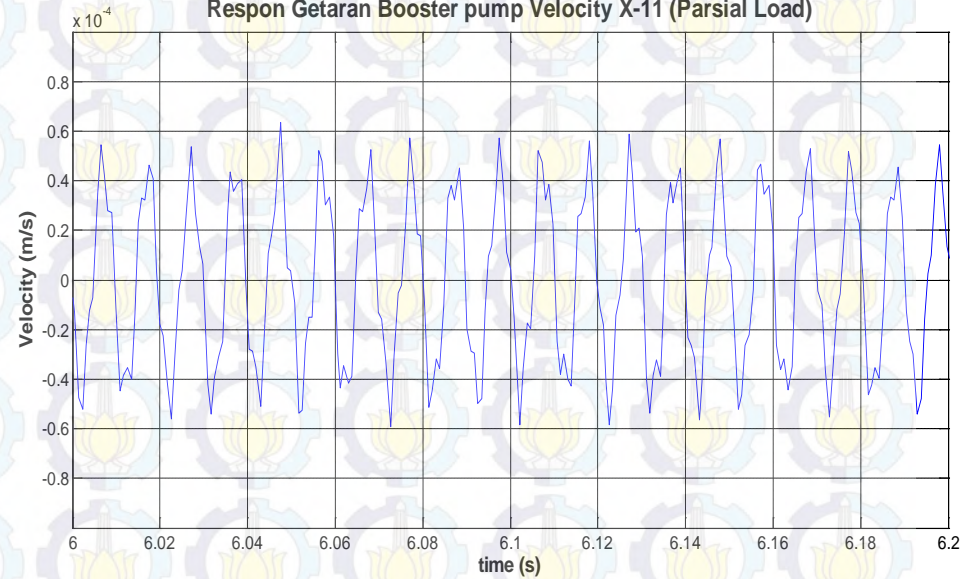


# Hasil Simulasi *Booster Pump*

Respon Getaran Booster pump Velocity X-11 (Max Load)

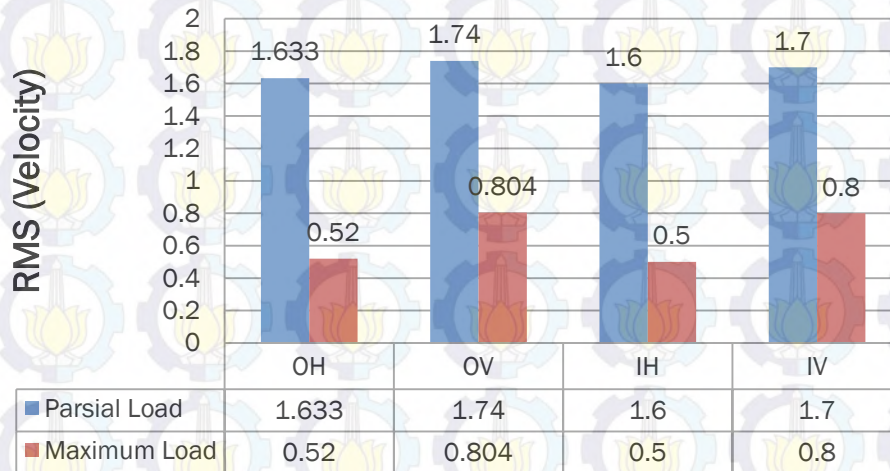


Respon Getaran Booster pump Velocity X-11 (Parsial Load)

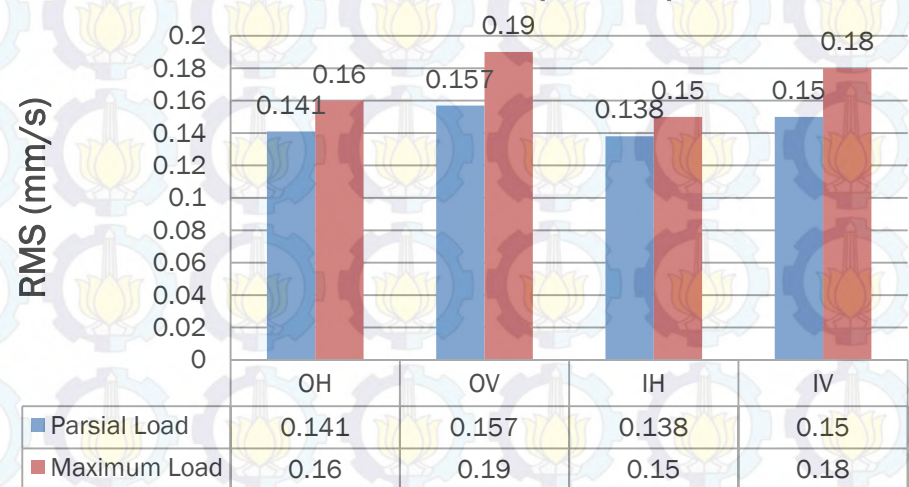


	Frekuensi
BFPM Max Load	99.6 Hz
BFPM Parsial Load	99.6 Hz

## Hasil Simulasi (Booster Pump)



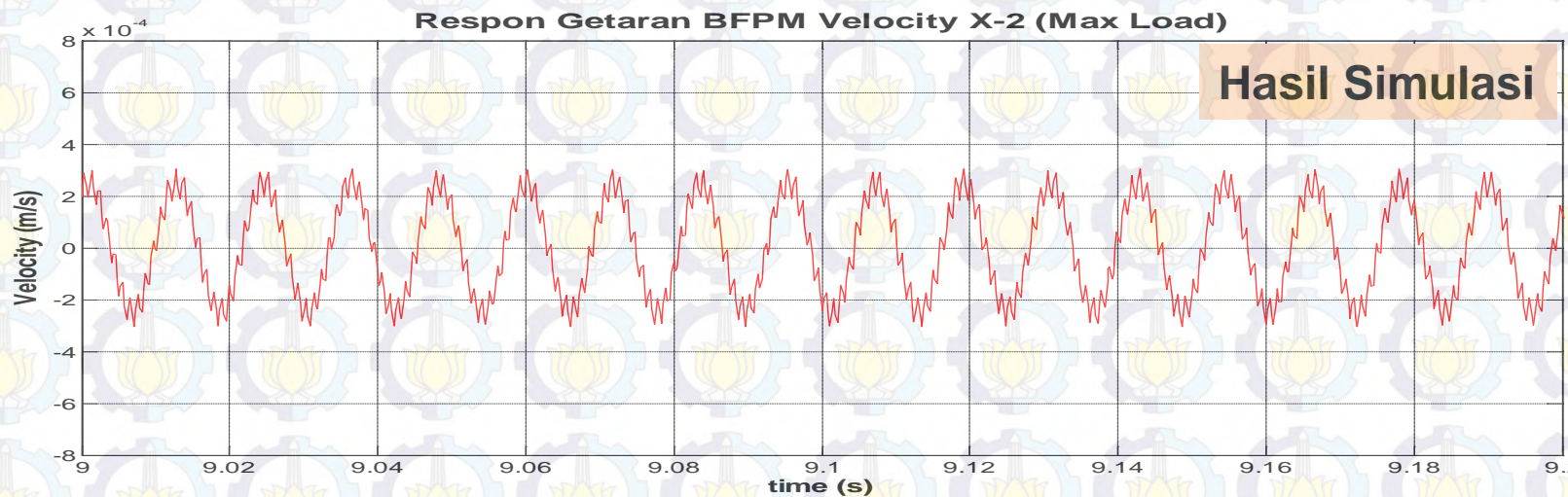
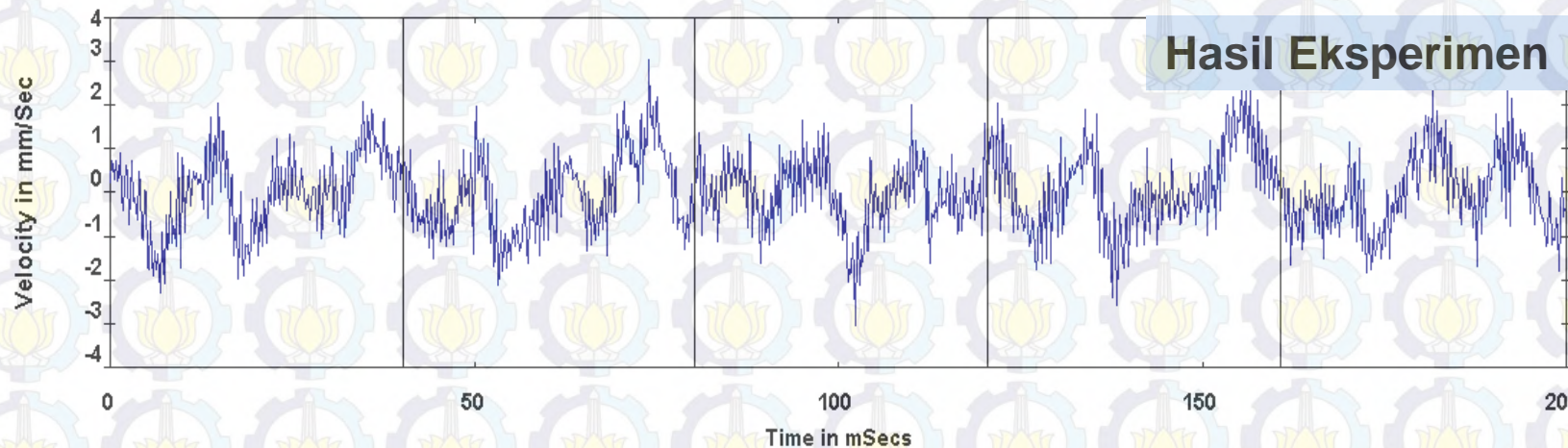
## Hasil Simulasi (BFPM)





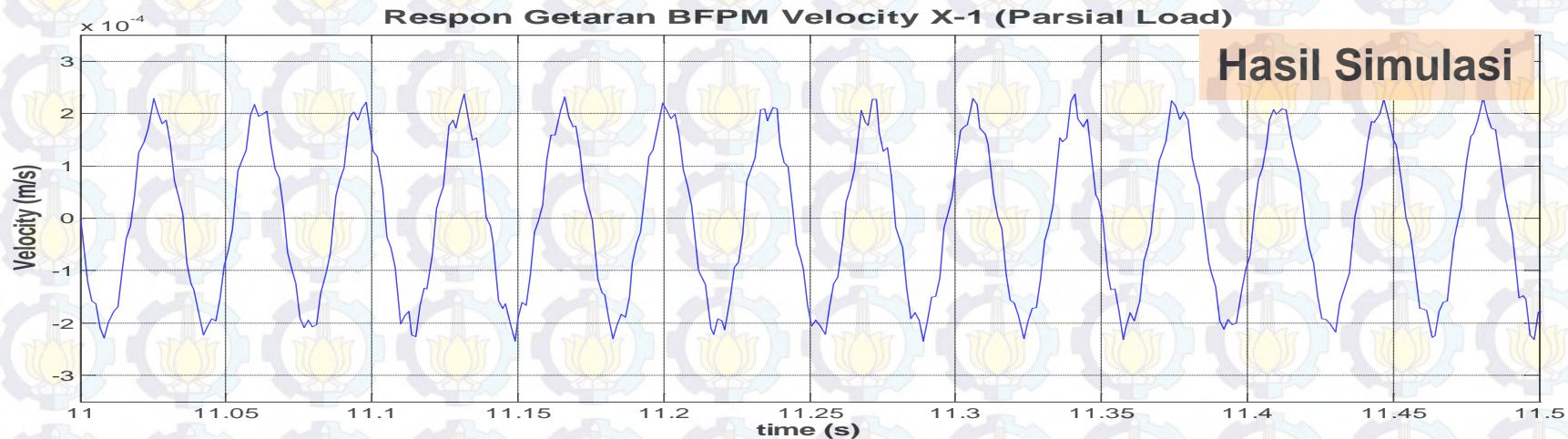
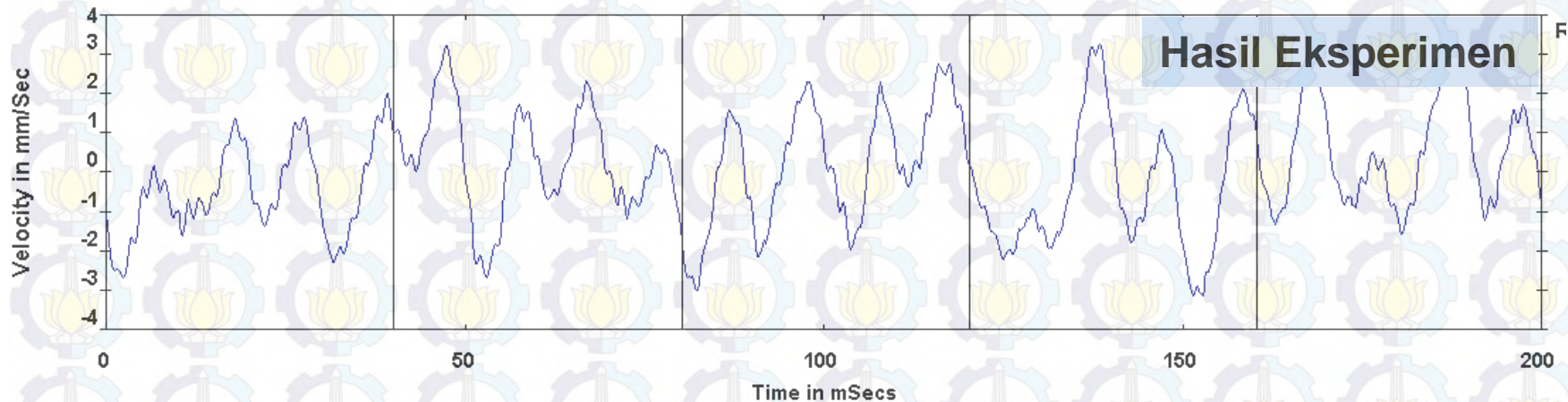
# Perbandingan Hasil Simulasi dan Eksperimen

## BFPM Beban Maksimum



# Perbandingan Hasil Simulasi dan Eksperimen

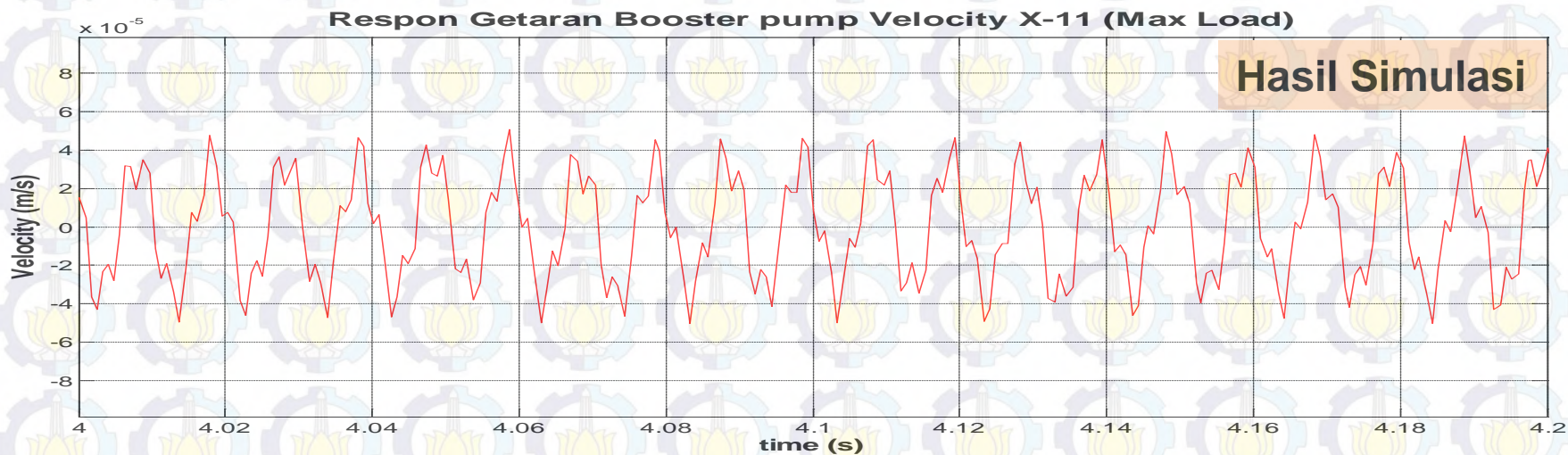
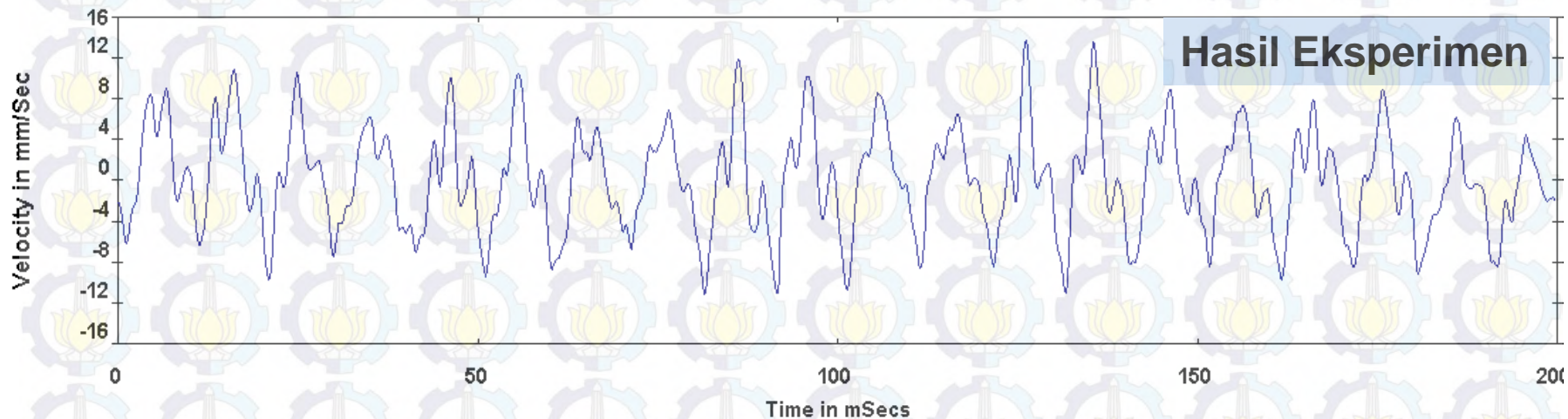
## BFPM Beban Parsial





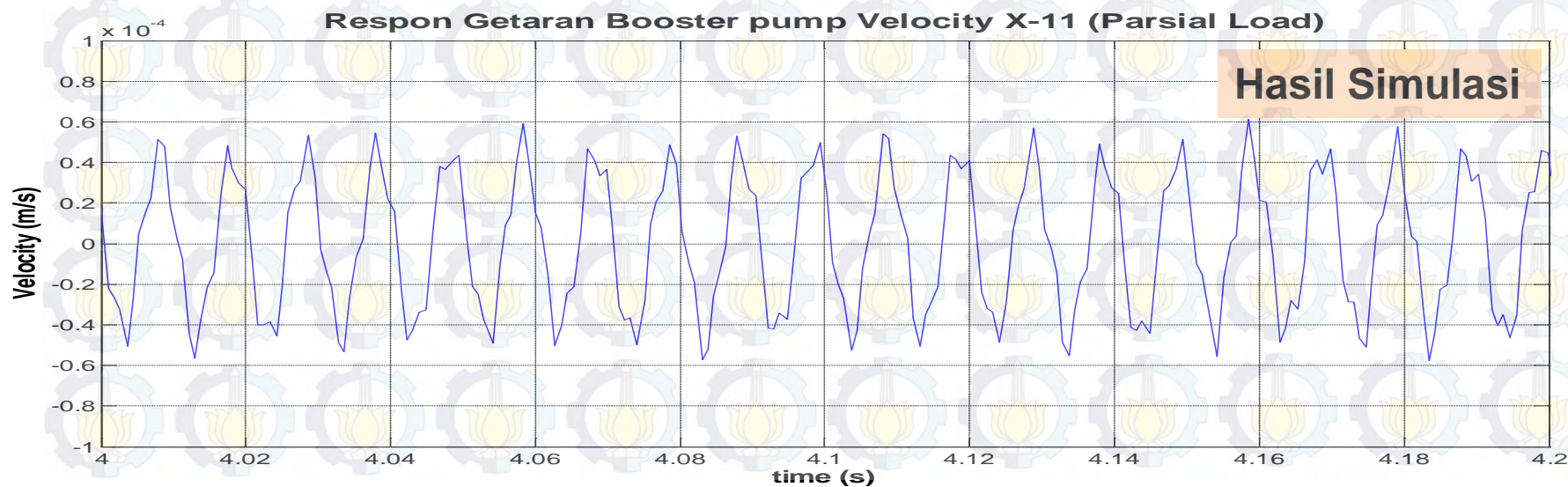
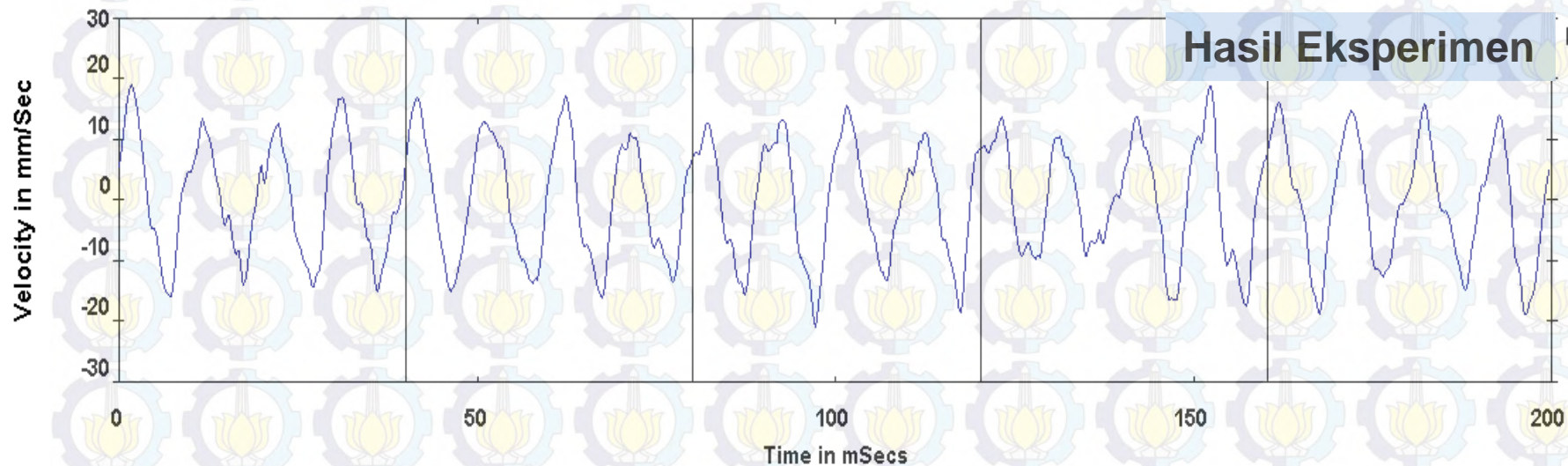
# Perbandingan Hasil Simulasi dan Eksperimen

## Booster Pump Beban Maksimum



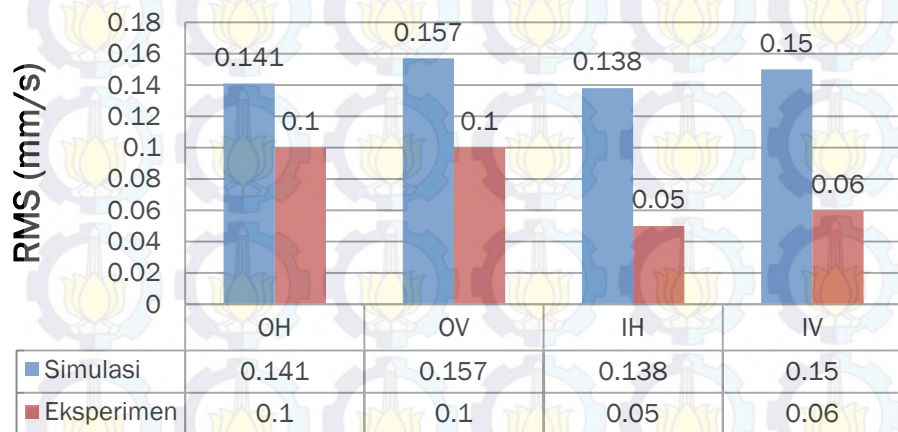
# Perbandingan Hasil Simulasi dan Eksperimen

## Booster Pump Beban Minimum





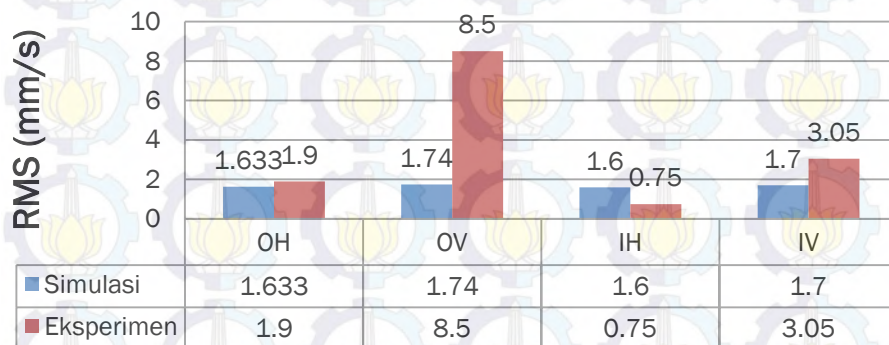
## Perbandingan Simulasi & Pengukuran Parsial Load (BFPM)



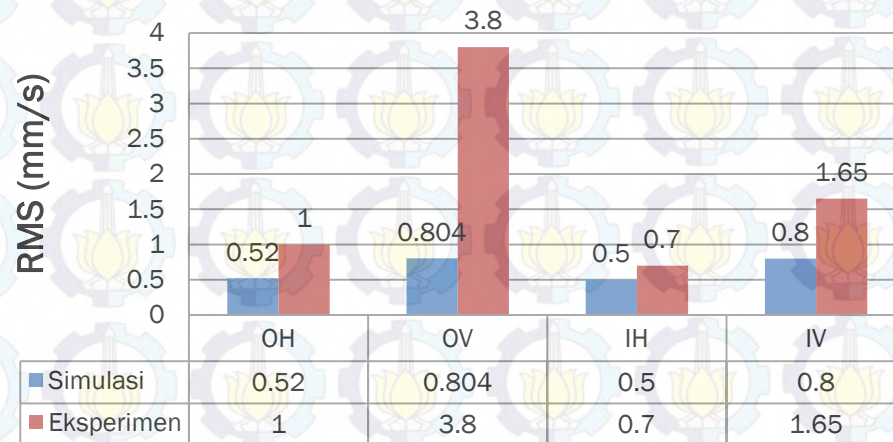
## Perbandingan Simulasi & Pengukuran Maksimum Load (BFPM)



## Perbandingan Simulasi & Pengukuran Parsial Load (Booster Pump)



## Perbandingan Simulasi & Pengukuran Maksimum Load (Booster Pump)





1. Tren vibrasi *boiler feed pump* pada beban maksimum lebih tinggi dibanding beban parsial hal ini disebabkan gaya dinamis akibat *hydraulic unbalance* yang lebih tinggi pada beban maksimum dibanding saat beban parsial, namun tren vibrasi *booster pump* pada beban maksimum lebih rendah daripada beban parsial, hal ini disebabkan gaya dinamis akibat *blade pass force* pada beban parsial yang lebih tinggi dibanding pada saat beban maksimum.
2. Gaya dinamis akibat *blade pass force* pada *booster pump* lebih tinggi daripada gaya dinamis akibat *hydraulic unbalance* pada *boiler feed pump* sehingga tren respon getaran pada *booster pump* lebih tinggi daripada *boiler feed pump* baik pada kondisi beban maksimum maupun beban parsial.



3. Tren respon vibrasi pada arah vertikal lebih tinggi daripada arah horizontal hal ini disebabkan oleh faktor koreksi sebesar 20% lebih tinggi pada arah vertikal, untuk semua kondisi pembebanan pada *boiler feed pump* maupun pada *booster pump*.
4. Tren vibrasi pada sisi *outboard* lebih besar daripada sisi *inboard* baik pada *boiler feed pump* maupun pada *booster pump*, hal ini disebabkan karena panjang sisi *outboard* terhadap titik beratnya yang lebih panjang daripada sisi *inboardnya*.
5. Respon getaran pada pompa dapat dimodelkan dengan 6 derajat kebebasan, dimana spektrum getaran antara hasil simulasi dan hasil eksperimen *boiler feed pump* maupun *booster pump* memiliki kesesuaian bentuk spektrum dan *trend rms velocity* menunjukkan *trend* yang sama pada sisi horisontal, vertikal, *inboard* dan *outboard*.



1. Perlunya kajian lebih lanjut untuk memodelkan sistem getaran dengan menggunakan gaya eksitasi akibat fluktuasi tekanan pada sisi *discharge* maupun sisi *suction* pompa.
2. Perlunya kajian lebih lanjut untuk memodelkan sistem getaran dengan metode elemen hingga untuk mendapatkan hasil simulasi yang lebih akurat untuk berbagai kondisi pembebanan



- [1] Attia khalifa, dkk. (2009), "Experiments on Pressure Fluktuations in a High Pressure Double Volute Centrifugal Pump Under Part Load Conditions". *Proceeding of the Fourth International Conference on Thermal Energy: Theory and Application*.
- [2] Amit Suhane. (2012), "Experimental Study on Centrifugal Pump to Determine the Effect of Radial Clearance on Pressure Pulsations, Vibration and Noise". *International Journal of Engineering Research and Applications (IJERA)*, Vol.2.
- [3] Stefan Berten. (2010), "Hydrodynamics of High Specific Power Pump for Off-Design Operating Conditions". *Thesis*.
- [4] Dr. Elemer Makay (1976), "Problems Encounter in Boiler Feed Pump Operation". Energy Research & Consultants Corporation.
- [5] Rao, Singiresu S. (2004). *Mechanical Vibration*. Prentice Hall PTR: Singapore.
- [6] Frederick, Close. (2002). *Modeling and Analysis of Dynamic System*. John Wiley & Sons: USA.
- [7] Garibotti. (2003). *Centrifugal Pump Handbook*. TMP S.p.A Termomeccanica Pompe-La Spezie-Italy.
- [8] Technical Documentation Instruction Manual. *Geared Variable Speed Coupling*. Voith Turbo.
- [9] *Feedwater Pump Operating Manual*. Shenyang Blower Works (Group) Co, Ltd.
- [10] Kaspul Anuar, ST. (2014). *Karakteristik Gaya Redaman Dan Energi Bangkitan Dari Regenerative Shock Absorber Dengan Motor Hidrolik*. Institut Teknologi Sepuluh Nopember, Surabaya.
- [11] Gulich, Johann Friedrich. (2008). *Centrifugal Pumps*. Springer.



**TERIMA KASIH**

***Mohon Saran/Masukanya***

